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Deposited in Mass: District Clerk's office 10th July 1837 see vol. 12. page 26

THE

BOSTON SCHOOL COMPENDIUM

Richard G. Parker

OF

NATURAL AND EXPERIMENTAL

Author of Book

PHILOSOPHY,

Parker

EMBRACING THE ELEMENTARY PRINCIPLES OF

MECHANICS,
PNEUMATICS,
HYDRAULICS,
HYDROSTATICS,
ACOUSTICS,
PYRONOMICS,
OPTICS,
ASTRONOMY,
ELECTRICITY,
GALVANISM,
MAGNETISM, and
ELECTRO-MAGNETISM;

WITH A DESCRIPTION OF THE

STEAM AND LOCOMOTIVE ENGINES.

Rec? at the Dep Oct 7 1837

BY RICHARD GREEN PARKER, A. M.

Principal of the Johnson Grammar School, Boston, (late Principal of the Franklin School,) author of "Progressive Exercises in English Composition," "Progressive Exercises in English Grammar," "Progressive Exercises in Rhetorical Reading," &c.

"Delectando pariterque monendo,
"Prodesse quam conspici."

BOSTON:
MARSH, CAPEN & LYON.
1837.

Printed by William A. Hall & Co.

To the Honorable

Samuel Atkins Eliot,

Mayor of the City of Boston,

and

Chairman of the School Committee.

SIR,

The public Schools of this City are under many obligations to you, for the interest you have taken in them, and for your disinterested exertions for their improvement. This volume, designed to supply a want which they have long felt, affords an opportunity of acknowledging the obligation, which I gladly embrace. The gratification which I feel in seeing you at the head of our municipal institutions, I beg leave to express in borrowed language:—

Tibi ut gratuler non est in animo; sed contra, hanc occasionem, mihi sic oblatam, nostram civitatem gratulandi, reniti non possum. Quæ omnia solita tua benevolentia ut accipias quæso.

I am, Sir,

Very respectfully,

Your obedient Servant,

Richard Green Parker.

PREFACE.

The School Committee of the City of Boston having recently furnished the Grammar Schools with apparatus for exemplifying the principles of Natural Philosophy, the author of this work, who, for ten years, has been at the head of one of these large establishments, and has felt the want of an elementary treatise *unencumbered with extraneous matter*, has been induced to attempt to supply the deficiency. If he is not deceived in the result of his labors, the work will commend itself to notice, by the following features:

1. It is adapted to the *present state* of natural science; embraces a wider field, and contains a greater amount of information on the respective subjects of which it treats, than any other elementary treatise of its size.

2. It contains an engraving of every article in *the Boston School set of philosophical apparatus;* a description of each instrument, and an account of the experiments which can be performed by means of the apparatus.

3. It is enriched by a representation and a description of the *Locomotive*, as well as the common *Steam Engine.*

4. Besides embracing a copious account of the principles of Electricity and Magnetism, its value is enhanced by the introduction of the science of Pyronomics, together with the new science of Electro-Magnetism.

5. It is peculiarly adapted to the convenience of study and of recitation, by the figures and diagrams being first placed, side by side with the illustrations, and then repeated on separate leaves at the end of the volume. The page and the number are also given, where each principle may be found, to which allusion is made, throughout the volume.

6. It presents the most important principles of science in a larger type; while the illustrations, and the deductions from these principles are contained in a smaller letter. Much useful and interesting matter is also crowded into notes at the bottom of the page. By this

arrangement, the pupil can never be at a loss to distinguish the parts of a lesson which are of primary importance; nor will he be in danger of mistaking theory and conjecture for fact.

7. It contains a number of original illustrations, which the author has found more intelligible to children, than those with which he has met elsewhere.

8. Nothing has been omitted, which is usually contained in an elementary treatise.

A work of this kind, from its very nature, admits but little originality. The whole circle of the sciences consists of principles deduced from the discoveries of different individuals, in different ages, thrown into common stock. The whole, then, is common property, and belongs exclusively to no one. The merit, therefore, of an elementary treatise on natural science must rest solely on the judiciousness of its selections. In many of the works from which extracts have been taken for this volume, the author has found the *same language* and expressions without the usual marks of quotation. Being at a loss, therefore, whom to credit for some of the expressions which he has borrowed, he subjoins a list of the works to which he is indebted, with this general acknowledgment; in the hope that it may be said of him as it was once said of the Mantuan Bard, that "he has *adorned* his thefts, and polished the diamonds which he has stolen."

The thanks of the author are due to Dr. J. W. Webster, Professor of Chemistry, in Harvard University, for the exhibition and explanation of a new and highly interesting apparatus in the department of Electro-Magnetism, to which allusion is made in the body of this work.

It remains to be stated, that the Questions, at the bottom of the page, throughout the volume, were not written by the author, but were prepared by one of the teachers of the school with which he is connected.

12 Orange Street, April, 1837. R. G. P.

LIST OF WORKS

Which have been consulted, or from which extracts have been taken, in the preparation of this volume.

Annals of Philosophy; Arnott's Elements of Physic; Bigelow's Technology; Cambridge Physics; Chambers' Dictionary; Enfield's, Olmsted's, Blair's, Bakewell's, Draper's, Grund's, Jones', Comstock's, and Conversations on Natural Philosophy; Franklin's Philosophical Papers; Henry's Chemistry; King's Manual of Electricity; Lardner on the Steam Engine; Library of Useful Knowledge; Paxton's Introduction to the Study of Anatomy; Pambour on Locomotive Engines on Railways; Phillips' Astronomy; Silliman's Journal of Science; Singer's Electricity; Scientific Class Book; Scientific Dialogues; Smith's Explanatory Key; The Year Book; Turner's Chemistry; Wilkins' Astronomy; Worcester's and the American School Geography.

ERRATA.

Page 35, No. 123, for "*to which a revolving body is confined,*" read "*around which all the parts of a body move.*" Page 36, No. 133, for "*round*" read "*around.*" Page 38, No. 199, in the illustration of fig. 13, it should be stated that "*the constantly increasing force of gravitation*, not the resistance of the air, brings the ball to E." Page 41, No. 146, after the words "*in the same point,*" insert "*with the centre of magnitude.*" Page 46, *dele* the first note. Page 57, No. 184, for "*male* and *female*" read "*convex* and *concave*;" make, also, the same correction in the *illustration.* Page 71, No. 217, for "*ascertainad*" read "*ascertained.*" Page 76, No. 233, *Illustration*—for "fig. 58," read "fig. 59," and in the third note, on the same page, transpose the words "*longer* and *shorter.*" Page 78, No. 240, for "*uniform*" read "*aeriform.*" Page 133, No. 352, insert the following: "*That part of the Science of Optics which treats of refracted light, is called Dioptrics.* Page 166, 38th line, for "*fluids*" read "*fluid.*" Page 194, in figure 194, for "*Sagitarius*" read "*Sagittarius.*" Page 193, No. 455, dele the words "*orbit of the earth is called the ecliptic. In other words, the* ;" and in fig. 135, page 195, for "*Murcury*" read "*Mercury.*"

NATURAL PHILOSOPHY.

SECTION I.

Divisions of the Subject.

1. NATURAL PHILOSOPHY is the science which treats of the powers and properties of natural bodies, their mutual action on one another, and the laws and operations of the material world.

The principal branches of Natural Philosophy, are Mechanics, Pneumatics, Hydraulics, Hydrostatics, Acoustics, Pyronomics, Optics, Astronomy, Electricity, Galvanism, Magnetism, and Electro-Magnetism.

2. Mechanics is that branch of Natural Philosophy which relates to motion and the moving powers, their nature and laws, with their effects in machines, &c.

3. Pneumatics treats of the nature, properties, and effects of air.

4. Hydraulics treats of the motion of fluids, particularly of water; and the construction of all kinds of instruments and machines for moving them.

5. Hydrostatics treats of the nature, gravity, and pressure of fluids.

6. Acoustics treats of the nature and laws of sound.

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1. What is Natural Philosophy? What are the principal branches of Natural Philosophy? 2. What is Mechanics? 3. Of what does Pneumatics treat? 4. Hydraulics? 5. Hydrostatics? 6. Acoustics?

7. Pyronomics treats of heat, the laws by which it is governed, and the effect which it produces.

8. Optics treats of light, colors, and vision, or sight.

9. Astronomy treats of the heavenly bodies, such as the sun, moon, stars, comets, planets, &c.

10. Electricity treats of thunder and lightning, and the causes by which they are produced, both naturally and artificially.

11. Galvanism is a branch of Electricity.

12. Magnetism treats of the properties and effects of the magnet, or loadstone.

13. Electro-Magnetism treats of the combined powers of Electricity and Magnetism.

SECTION II.

Of Matter and its Properties.

14. Matter is the general name of every thing that occupies space, or has figure, form or color.

The words substance, body, or bodies, are but different names for the same thing, and they are all comprehended under the general name of matter.

15. All matter is composed of very minute particles, which are connected together in different bodies, by different degrees of cohesion.

16. Those bodies in which these particles strongly adhere are hard bodies; and those in which the cohesion is not strong are soft. It is therefore owing to the different degrees of cohesion, that some bodies are hard and others soft.

17. Matter exists in two forms, namely, a solid and a fluid form.

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7. Of what Pyronomics? 8. Optics? 9. Astronomy? 10. Electricity? 11. Of what is Galvanism a branch? 12. Of what does Magnetism treat? 13. Electro-Magnetism? 14. What is Matter? What is meant by the words substance, body, or bodies? 15. Of what is all matter composed? How are these particles connected together? 16. What bodies are hard? What soft? To what is it owing that some bodies are hard and others soft? 17. In how many forms does matter exist? What are they?

18. Matter exists in a solid form when the particles of which it is composed adhere together, so that one particle cannot be moved without moving the whole.

19. Matter exists in a fluid form when the particles, having but a slight degree of cohesion move easily among themselves.

20. There are seven essential properties belonging to all matter, namely: 1. Impenetrability, 2. Extension, 3. Figure, 4. Divisibility, 5. Indestructibility, 6. Inertia, and 7. Attraction.

These are called essential properties, because no particle of matter can be deprived of them, or exist without them.

21. There are certain other properties existing in different bodies, called accidental properties, because they do not necessarily exist in the bodies themselves, but depend upon their connexion with other bodies. Thus, color and weight are accidental properties, because they do not necessarily exist in the bodies that possess them, but depend upon their connexion with other things. [See *Gravity* and *Optics*.]

22. There are also certain terms used in Natural Philosophy, to express the state in which matters exists, such as Porosity, Density, Rarity, Compressibility, Expansibility, Mobility, Elasticity, Brittleness, Malleability, Ductility and Tenacity.

23. By Impenetrability is meant the power of occupying a certain space, so that where one body is, another cannot be, without displacing it; because two bodies, or two portions of matter cannot occupy the same space at the same time.

24. Impenetrability belongs to fluids as well as solid bodies; and it is as impossible for a liquid and a solid body to occupy the same space at the same time, as it is for two solid bodies to do so. The reason why fluids appear less impenetrable than solid bodies, is, that

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18. When does matter exist in a solid form? 19. When in a fluid form? 20. How many essential properties of matter are there? What are they? Why are they called essential properties? 21. What other properties exist in different bodies? Why are they called accidental properties? Are color and weight essential or accidental properties? Why? 22. What terms are used in Philosophy to express the state in which matter exists? 23. What is meant by Impenetrability? 24. Does Impenetrability belong to fluids? Why do fluids appear less impenetrable than solid bodies?

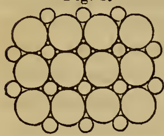
the particles of which they are composed move easily among themselves, on account of their slight degree of cohesion. [See No. 19.]

Illustration 1st. Fill a tumbler with water, or any other liquid, and put a spoon, or any other article in it,—the liquid will flow over the sides of the vessel to make room for the spoon.

Illustration 2d. Put some water into a tube closed at one end; and then insert a piece of wood that fits the inside of the tube very accurately. It will be impossible to force the wood to the bottom of the tube, unless the water is first removed. The same experiment may be made with air instead of water; and proves that water, air, and all other fluids, are equally solid, or impenetrable, with the hardest bodies.

25. The particles of fluids are supposed to be round, and therefore touch one another only in a few points. There will be spaces between the particles of fluids, in the same manner that there are between large balls which are piled on one another. Between these spaces other smaller balls may be placed; and these smaller balls, having spaces between them, will admit others still smaller; as may be seen in Fig. 1.

Fig. 1.



It may thus be perceived, that all substances. whose particles are globular, or round, have vacant spaces between the particles, which can never be filled. For this reason, a certain quantity of salt, the particles of which are smaller than those of water, can be put into a vessel full of water, without causing it to overflow; and as the particles of which sugar is composed are smaller than those of salt, a portion of sugar may be added after the fluid is saturated with salt.

26. The impenetrability of water was shown by an experiment made at Florence, many years ago. A hollow globe of gold was filled with water, and submitted to great pressure. The water was seen to exude through the pores of the gold and covered it with a fine dew. [See note under No. 196.]

27. When an open phial is plunged into a basin of water, the air will rush out in bubbles to make room for the water; and if an inverted tumbler or goblet be im-

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What examples are given in Illustration 1st and 2d to prove the impenetrability of fluids? 25. What is supposed to be the form of the particles of fluids? What follows from this? What figure illustrates this? What is said in regard to all bodies whose particles are round or globular? What examples are given to prove this? 26. What example can you give to prove the impenetrability of water? 27. What the air?

mersed in water, the water will not rise in the tumbler unless it be inclined so that the air can escape. These are further proofs of the impenetrability of air.

28. When a nail is driven into wood, or any other substance, it forces the particles asunder, and makes its way between them; but not a single atom of the wood can remain in the same space that the nail occupies; and if the wood is not increased in size by the addition of the nail, it is because wood is a porous substance, like sponge, the particles of which may be compressed or squeezed more closely together. It is thus they make way for the nail.

29. By extension, is meant length, breadth and depth. Bulk and size are but different names for extension. It is evident that every body, or portion of matter must have size, bulk, or extension, which is measured by the portion of space which it occupies.

30. The different terms which are used to express the extension of a body are length, breadth, width, height, depth and thickness. Length is the extent from end to end. Breadth or width is the extent from side to side. Height, depth and thickness, are the extent from the top to the bottom. The measure of a body from the bottom to the top is called height, from the top to the bottom is called depth. Thus we speak of the depth of a well, the height of a house, &c. Thickness is a term applied to solid bodies only, and implies the extent from the upper to the under surface.

31. By figure, is meant the form or shape of a body; and it differs from extension, in the quantity of matter it contains. Thus two circles, or two balls may be of the same shape or figure, while they differ in extension as the one exceeds the other in the quantity of matter which it contains, and consequently will occupy more space.

32. By Divisibility, is meant susceptibility of being divided. A body, however small, can be divided into halves, quarters, &c.; and these halves and quarters

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28. What solids? 29. What is meant by Extension? 30. What terms are used to express the extension of a body? What is length? Breadth? Height, depth and thickness? What is the difference between height and depth? What is thickness? 31. What is meant by figure? How does it differ from extension? Give an example to show the difference. 32. What is meant by Divisibility?

may be again divided in the same manner, although they may be too small to be visible to our eyes. There are some living creatures called animalcula,so small that we cannot see them. To them a grain of sand appears as large as a mountain does to us. Our power of dividing matter ends where theirs begins; and it follows that this divisibility of matter is limited only by the extent of our powers. If, therefore, by means of cutting, pounding, grinding, &c., we divide a body into as small particles as we can, these particles will still have an upper and an under surface, with length, breadth, and thickness, all of which will still be visible to such creatures as have sufficient powers of vision.

33. The extreme divisibility of matter may be shown in a number of ways. *First.* By melting a solid body in a liquid. When, for instance, we sweeten a cup of tea or coffee, a small portion of sugar is dissolved and diffused through the whole of the liquid.

Secondly. From the manner in which we smell odoriferous substances. The perfume or odor of a body is produced by the escape of very minute particles which enter the nostrils. This perfume is diffused through the whole extent of a large room, without the loss of the smallest visible part of the substance.

Thirdly. A few drops of a colored liquid falling into a vessel of water, immediately tinges the whole of the water with the color, and must, therefore, be diffused throughout it.

Fourthly. A lighted candle, placed upon a hill, diffuses particles of light through the space of a mile in extent, before it has lost any visible portion of its substance.

Fifthly. It has been calculated that sixteen ounces of gold, which in the form of a cube would not measure an inch and a quarter in its side, will completely gild a quantity of silver wire twenty-five thousand miles in length.

Sixthly. A single grain of gold may be hammered by a gold-beater until it will cover fifty square inches;

By what is the divisibility of matter limited? 33. Mention some example to show the extreme divisibility of matter. What do these examples prove?

each square inch may be divided into two hundred strips; and each strip into two hundred parts, which may be seen with the naked eye. Each square inch, therefore, contains forty thousand visible parts, which, multiplied by fifty, the number of square inches which a grain of gold will make, gives two million parts, each of which can be seen with the naked eye. From all which it appears that matter is infinitely divisible.

34. The particles which escape from luminous or odoriferous objects, although they are too small to be visible, all form a part of the substance of those objects, and a body is in reality diminished by their escape. This is evident in liquid bodies; as, for instance, in a bottle of lavender water, which, if left unstopped a sufficient length of time, will evaporate and disappear.

35. The steam which arises from boiling water is nothing more than portions of the water heated. The heat insinuates itself between the particles of the water and forces them asunder. When deprived of the heat, the particles will unite together in the form of drops of water.

Experiment. Hold a cold plate over boiling water. The steam arising from the water, will unite in drops on the bottom of the plate.

36. The air which we breathe generally contains a considerable portion of moisture or water. On a cold day this moisture condenses on the glass in the windows, and becomes visible. We see it, also, collected in drops on the ouside of a tumbler or other vessel containing cold water, in warm weather.

37. By the Indestructibility of matter is meant that it cannot be destroyed. It may be indefinitely divided, or altered in its form, color and accidental properties, but it must still continue to exist in some form through all its changes of external appearance.

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34. Are odoriferous and luminous bodies diminished by the particles which escape from them? Why can we not see the particles which escape? Give an example to prove that the bodies are diminished. 35. Of what is the steam, which arises from boiling water, composed? How are the particles separated? When deprived of heat what will become of them? What experiment is given to prove this? 36. Does the air which we breathe contain any moisture? Give an example to prove it. 37. What is meant by the indestructibility of matter?

38. The science of chemistry teaches us that there is a certain definite number of elementary substances, of some one or more of which all other substances are composed. The powers of man, or of nature, can change the shape, the combination, or the situation of these elementary substances, but nothing short of creative power can annihilate any one of them.

Illustration Ist. Thus water, for instance, which was formerly considered as a simple substance, is found to consist of two substances, almost imperceptible to the sight, called hydrogen and oxygen, united by what is called chemical attraction. These substances may be separated and made to unite with other substances, but they cannot be destroyed.

Illustration 2d. There is actually no more nor less water existing at the present time than there was at the creation of the world, but it exists only in different forms or situations. When water disappears, either by boiling over a fire, or evaporating by the heat of the sun, or, in other words, when "*it dries up*," it rises slowly in the form of steam or vapor. This vapor ascends in the air and constitutes clouds; these clouds again fall to the earth in the shape of rain, snow or hail, and form springs, fountains, rivers, &c. The water on or in the earth, therefore, is constantly changing its shape or situation, but no particle of it is ever actually destroyed.

Illustration 3d. The particles or simple substances of which wood or coal is composed, are not destroyed when the wood or coal is burnt. Part of them arise in smoke or vapor and the remainder is reduced to ashes. A body in burning undergoes remarkable changes. It is subdivided—its form and color are altered—its extension is increased, but the various parts into which it has been separated by combustion, continue in existence and retain all the essential properties of bodies.

Illustration 4th. Every thing in nature decays and is corrupted in the lapse of time. We ourselves die, and our bodies moulder in the dust; but not a single atom of them is lost. They serve to nourish the earth, whence, while living, they drew their support, and by degrees become incorporated with other substances.

39. By Inertia, is meant the resistance which inactive matter makes to a change of state, whether of motion or rest. A body at rest cannot put itself in motion, nor can a body in motion stop itself.

40. A body, when put in motion, will continue to move

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38. What does chemistry teach with regard to the composition of bodies? Can any particle of matter be annihilated? Of what is water composed? Is there more or less water existing now than there was at the creation of the world? What becomes of water when it evaporates? What becomes of the particles or simple substances of different kinds of fuel when burnt? What becomes of every thing in nature? 39. What is meant by Inertia? 40. How long will a body in motion continue to move, unless it be stopped?

forever, unless it be stopped. When a stone or ball is thrown from the hand, there are two forces which continually operate to stop it; viz. the resistance of the air, and gravitation: all motion which is caused by animal or mechanical power, will be destroyed by the combined action of these forces. But could these obstacles be removed, the body in motion would continue to move forever.

41. The Inertia, or resistance of a body to a change of state, as, for instance, a ball, may be perceived by throwing it from the hand. It requires a considerable degree of strength to give it a rapid motion; and the person who stops or catches it, feels the resistance it makes to being stopped.

42. The degree of motion in a moving body, or the force which it will require to stop it when in motion is called its *momentum*, and is calculated by its velocity, its size, and its weight, or the quantity of matter which it contains. The smaller its size,* and the greater its weight and its velocity, the greater will be its momentum.

Illustration. Thus, if a body weighing six pounds, move at the rate of two miles in a second of time, its momentum may be represented by six, multiplied by two, which is equal to twelve. If a body weighing twelve pounds, move at the rate of four miles in the same time, its momentum will be represented by twelve, multiplied by four, which is equal to forty-eight.

43. Attraction expresses the tendency which different bodies or portions of matter have to approach each other. Every portion of matter is attracted by every other portion of matter, and this attraction is the strongest in the largest portions.

* The resistance of the air will be less on a small body than on a large body. Could this resistance be removed, the momentum of a body would depend only on its velocity and weight.

When a stone or ball is thrown from the hand how many forces continually operate to stop it? What are they? What destroys the motion caused by animal or mechanical power? How could a body in motion be made to move forever? 41. What example is given to show the Inertia of a body? 42. What is the momentum of a body? How is it calculated? Upon what does the momentum of a body depend? Is the resistance of the air less on a large or small body? If this resistance could be removed, upon what would the momentum depend? What illustration is given? 43. What is attraction? Where is attraction the strongest?

44. As the earth is the largest portion of matter with which we are practically acquainted, every thing on or near its surface, is attracted towards it. For this reason every thing about us will fall to the ground or the surface of the earth, unless it is prevented.

45. The attraction of all masses of matter is in a direct proportion to their quantity, and in inverse proportion to their distances from each other. That is, the greater the quantity and the less the distance, the stronger will be the attraction.

46. There are two kinds of attraction belonging to all matter, namely, the attraction of gravitation, or GRAVITY, and the attraction of cohesion, or COHESIVE ATTRACTION.

47. The attraction of gravitation, or gravity, is that which causes bodies at a distance to approahc each other.

48. The attraction of cohesion, or cohesive attraction, is that which unites the particles of a body. [See No. 16.]

49. By the attraction of gravity a stone falls to the ground.

50. By the attraction of cohesion, the particles which compose the stone are held together.

51. The difference between the two kinds of attraction is this: the attraction of cohesion takes place in very minute particles, and at very small distances; the attraction of gravity acts on the largest bodies and at immense distances. The attraction of cohesion takes place between the particles of the same body. The attraction of gravitation causes different bodies to approach each other.

52. The attraction of gravitation causes weight; or, in other words, weight is but another name for attraction. When we say that a body weighs an ounce, a pound, or a hundred pounds, we express by these terms, the degree of attraction by which it is drawn to-

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44. Why is every thing attracted towards the earth? 45. In what proportion does attraction increase? 46. How many kinds of attraction are there belonging to all matter? What are they? 47. What is the attraction of gravitation, or gravity? 48. What is the attraction of cohesion, or cohesive attraction? 49. What causes a stone to fall to the ground? 50. By what are the particles which compose the stone held together? 51. What is the difference between these attractions? 52. What is weight? When we say a body weighs an ounce, or a pound, what do we express by this term?

wards the earth. As this attraction, (as was stated in number 43,) depends upon the quantity or portion of matter there is in a body, it follows that those bodies which are heaviest, that is, which are most strongly attracted, contain the most matter.

53. We estimate the quantity of matter in a body, not by its apparent size but by its weight. Some bodies, as cork, feathers, &c., are light; others, as lead, gold, mercury, &c. are heavy. The reason of this is that the particles which compose the former are not closely packed together, and therefore they occupy considerable space; while in the latter they are joined more closely together, and occupy but little room. A pound of cork and a pound of lead, therefore, will differ very much in apparent size, while they are both equally attracted by gravity, that is, they weigh the same.

54. The particles of which bodies are composed touch one another in few places only. There are, consequently, small spaces between the particles, and these spaces are called pores. The porosity of a body implies, therefore, that it has pores; and the greater the number, and the larger the size of these *pores*, the more porous the body is said to be.

55. The porosity of bodies leads to another distinction, called density and rarity. By density is meant the closeness and compactness of the particles of a body. Rarity is the contrary of density, and implies the thinness or subtlety of bodies. A body in which the pores are small and few in number is called a *dense* body. When the pores are large and numerous, the body is said to be rare.

56. Dense bodies are always heavier than rare bodies of the same size, because there are a greater number of particles in the same space, and consequently the body is more strongly attracted. [See No. 53.]

Upon what does attraction depend? What follows from this? 53. How do we estimate the quantity of matter in a body? What bodies are light? What heavy? How do you account for this difference? 54. What are pores? What does the porosity of a body imply? Upon what does the porosity depend? 55. What is meant by Density? Rarity? When is a body called dense? When rare? 56. How do dense and rare bodies of the same size compare with regard to their weight? Why?

57. The strength of cohesive attraction in bodies, depends, in great measure, upon their density. This is particularly the case in fluids. The thinner and lighter a fluid is, the less is its cohesive attraction.

58. The cohesive attraction of solid bodies is much greater than that of fluids; because the particles of solids are more closely united.

59. The pores of substances are generally filled with air.

60. There is another fluid much more subtle than air, which pervades all bodies; namely, heat, which insinuates itself, more or less, between the particles of all bodies, and forces them asunder. Heat, and the attraction of cohesion constantly act in opposition to each other; and the more a body is heated, the more its particles will be separated.

61. The effect of heat in separating the particles of different kinds of substances is seen in the melting of solids, such as metals, wax, butter, &c. The heat insinuates itself between the particles, and forces them asunder. These particles then are removed from that degree of nearness or proximity to each other within which cohesive attraction exists, and the body is reduced to a fluid form. When the heat is removed the bodies return to their former solid state.

62. From what has now been stated, it appears, 1st. That cohesive attraction exists only between those particles which are, or appear to be, in absolute contact. 2d. That cohesive attraction is the strongest when the particles are in a state of closest contact. 3d. That the cause of the fluid form of bodies, is, that the paricles touch one another only in a few points, and therefore that cohesive attraction in them is weak. [See No. 19.]

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57. Upon what does cohesive attraction in a great measure depend? In what is this particularly the case? Upon what does the cohesive attraction of fluids depend? 58. In which is cohesive attraction the stronger, in solids or fluids? Why? 59. With what are the pores of all substances generally filled? 60. What fluid is more subtle than air? What effect has heat upon bodies? What two forces continually act in opposition to each other? 61. In what can the effect of heat be seen? How does it separate the particles? What would be the effect were the heat removed? 62. From what has been stated, what do you learn respecting cohesive attraction? First? Second? Third?

63. Of all the effects of heat, that produced upon water, is, perhaps, the most remarkable. The particles are totally separated and converted into steam or vapor, and their extension is wonderfully increased. [*See No.* 35.]

64. Heat also produces most remarkable effects upon air, causing it to expand to a wonderful extent, while the absence of heat causes it to shrink or contract into very small dimensions.

65. The attraction of cohesion causes the small watery particles which compose mist or vapor to unite together in the form of drops of water. It is thus that rain is produced. The clouds consist of mist or vapor expanded by heat. They rise to the cold regions of the skies, where they lose their heat; and then, uniting in drops, fall to the earth. But so long as they retain their heat, the attraction of cohesion can have no influence upon them, and they will continue to exist in the form of steam, vapor, or mist.

The attraction of cohesion also causes liquids to rise above their level in capillary tubes, or tubes the bores of which are exceedingly small. This is caused by the attraction between the particles of the liquid and the interior surface of the tube.

Experiment. The same effect is produced by two pieces of flat glass, joined together at one side, and separated at the other by a thin strip of wood, card, or other substance. When thus prepared, immerse the glass in colored water, having previously wet the inner surfaces. The water will rise between the pieces of glass, forming a beautiful curve, the highest part appearing where the pieces of glass are in contact.

66. All porous substances, such as sponge, bread, linen, sugar, &c., may be considered as collections of capillary tubes, and for this reason, water and other liquids will rise in them, when they are partly immersed.

67. By the Compressibility of bodies is meant the power of being compressed into smaller limits of ex-

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63. Upon what has heat the most remarkable effect? How does it effect it? 64. What effect has heat upon air? 65. How is rain produced? Of what do the clouds consist? What causes liquids to rise above their level in capillary tubes? How does it cause them to rise? What experiment is given to show the effect of capillary attraction? 66. What is the reason that liquids will rise in porous substances when only partially immersed in them? 67. What is meant by the compressibility of bodies?

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tension than they naturally have. Of this all substances are susceptible if a sufficient power be applied.

68. By the Expansibility of bodies, is meant the power of being increased in extension, and it is the reverse of Compressibility. Heat expands most substances, and cold contracts or compresses them.

69. By Mobility is meant the power of being moved. All bodies however large or heavy, may be moved, provided a sufficient power be applied.

70. Elasticity is the power which causes a body to resume its shape after being compressed or expanded. Thus when a bow or a cane is bent, it returns to its former shape as soon as the pressure is removed. When the flesh of a living animal is pressed, it in like manner resumes its shape on removing the pressure. Caoutchouc, or India-rubber likewise, on account of its elasticity, when bent or drawn out, will immediately return to its shape. But of all bodies, those in the form of gas, or air, are the most remarkable for this property. Hard bodies* are in the next degree elas-

* When two ivory or metallic balls strike each other, the parts at which they touch will be flattened, but no mark is perceptible, their elasticity instantly destroying all trace of it. If, however, a small spot of ink be placed on one of the balls at the point of contact, it will be found, after the contact, to have spread, and will thus show that there has been compression. The cause of elasticity is not well understood. Elasticity implies susceptibility of compression; and the susceptibility of compression depends upon the porosity of bodies; for were there no pores, or spaces between the particles of matter, of which a body is composed, it could not be compressed. But it is not the case that bodies whose particles are most distant from each other are the most elastic. Elasticity implies not only susceptibility of compression, but the power of restoring its former state after compression. The pores of such bodies as ivory and metals, are invisible to the naked eye; but it is well ascertained that gold, [*See No.* 26.] one of the most dense of all bodies is extremely porous, and that its pores are sufficiently large to admit water, under great pressure, to pass through them. In cork, sponge, and bread, the pores form considerable cavities; in wood, and many kinds of stone, when not polished, they are perceptible to the naked eye; whilst in ivory, metals, and most varnished and polished bodies they cannot be discerned. To give an idea of the extreme porosity of bodies, Sir Isaac Newton conjectured, that if the earth were so compressed as to be absolutely without pores, its dimensions might not be more than a cubic inch. The elasticity of ivory is very perfect, that is to say, it restores itself after compression, with a force very nearly equal to that exerted in compressing it. Liquids, such as water, &c. have scarcely any elasticity.

Can all bodies be compressed? 68. What is Expansibility? What effect has heat and cold upon bodies? 69. What is Mobility? 70. What is Elasticity? Give some examples of Elasticity. What bodies are most elastic? Which are the more elastic, hard or soft bodies? *Note.* What effect is produced when two ivory balls strike each other? What is the cause of Elasticity? Could a body without pores be compressed? Are those bodies most elastic whose particles are most distant? What does Elasticity imply? How has it been proved that gold is porous? [*See No.* 26.] What is said of the pores of cork, sponge, wood, stone, ivory, metals, &c.? What did Newton conjecture with regard to the pores of the earth? Which has the most elasticity, ivory or liquids?

tic. Soft bodies, such as clay, wax, tallow, butter, &c. have very little elasticity, and are called non-elastic bodies.

Malleability implies capability of being drawn under the hammer, or rolling-press. This property belongs to some of the metals, as gold, silver, iron, copper, &c., but not to all; and it is of vast importance to the arts and conveniences of life. Gold is the most malleable of all metals.

Brittleness is the property which renders substances easily broken, or separated into irregular fragments. This property belongs chiefly to hard bodies.

Iron, steel, brass and copper become brittle when heated and suddenly cooled; but if cooled slowly, they are not easily broken. Brittleness is not entirely opposed to elasticity; for some bodies, glass, for instance, are very brittle, and yet a ball, or fine threads of this substance, are highly elastic.

Brittleness is the opposite of malleability.

Ductility is that property which renders a substance susceptible of being drawn into wire. Platina is the most ductile of all metals. It can be drawn into wire scarcely larger than a spider's web. Malleability and ductility are different properties. Some substances which are malleable to a great degree have very little ductility; and on the contrary, some which are very ductile are not malleable.

Tenacity implies a great degree of cohesion among the particles of bodies. Steel is the most tenacious of all substances.

SECTION III.

Of Gravity or Weight, or the Attraction of Gravitation.

71. All matter is attractive, from the smallest particle to the largest mass; and bodies attract each other with a force proportionate to their density, that is, the quantity of matter they contain.

72. The earth being the largest mass of matter with which we are practically acquainted, attracts (*according to the principles stated in numbers* 43, 44 and 45) all things to itself. This attraction is called the attraction of gravitation.

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71. Is all matter attractive? In what proportion do bodies attract each other?
72. What is said of the attraction of the earth, and what is the attraction called?

73. The force of gravity is greatest at the surface of the earth, and decreases both upwards and downwards, but in different degrees.

74. The force of gravity decreases above the surface as the square of the distance from the centre increases. That is, gravity at the surface of the earth, which is about 4000 miles from the centre, is four times more powerful than it would be at double that distance, or 8000 miles from the centre.

75. According to the principle just stated, a body which at the surface of the earth weighs a pound, at the centre of the earth will weigh nothing.

1000	miles	from	the	centre	it	will weigh	one quarter of a pound.
2000	"	"	"	"	"	"	one half of a pound.
3000	"	"	"	"	"	"	three quarters of a pound.
4000	"	"	"	"	"	"	one pound.
8000	"	"	"	"	"	"	one quarter.
12000	"	"	"	"	"	"	one ninth, &c.

76. It follows from what has been stated, with regard to weight as a consequence of attraction, that if there were but one body in the universe, it would have no weight, because there would be nothing to attract it. But cohesive attraction would still exist, and keep the particles which compose the body united.

77. As the attraction between all bodies is mutual, it follows that when a stone or any heavy body falls to the earth, the earth will rise to meet it. But as the attraction is in proportion to the quantity of matter each contains, the stone will fall as much farther than the earth rises, as the earth exceeds the stone in bulk. Now the earth is one quatrillion, that is, one thousand million millions times larger than the largest body which has ever been known to fall through our atmosphere. Supposing, then, that such a body should fall through a distance of 1000 feet—the earth would rise no more than the hundred billionth part of an inch, a distance altogether imperceptible to our senses.

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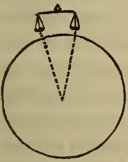
73. Where is the force of gravity greatest? 74. In what proportion does gravity decrease above the surface of the earth? 75. Give an example to show this. 76. If there were but one body in the universe, what would be its weight? Why? Would cohesive attraction exist? 77. Is the attraction between bodies mutual? What follows from this? Why do we not see the earth rise to meet falling bodies? What example is given to illustrate this?

78. The principle of mutual attraction, is not confined to the earth. It extends to the sun, the planets, comets and stars. The earth attracts each of them, and each of them attracts the earth, and these mutual attractions are so nicely balanced by the power of God, as to cause the regular motions of all the heavenly bodies, the diversity of the seasons, the succession of day and night, summer and winter, and all the grand operations which are described in astronomy.

79. The direction in which falling bodies approach the surface of the earth, is called a vertical, or plumb line. Such lines are every where perpendicular to the surface, and when prolonged will meet at the centre of the earth. For this reason no two lines suspended by weights will be parallel to each other. Even a pair of scales hanging perpendicular to the earth, are not exactly parallel, because they both point to the same spot, namely, the centre of the earth—but the convergency is so small, that their inclination is not perceptible to our senses. [*See Fig.* 2.] For the same reason no two bodies can fall to the earth in parallel lines.

No. 2.



80. According to the laws of attraction, all bodies at an equal distance from the earth will fall to it in the same space of time, if nothing impedes them. But the resistance of the air makes bodies of different density fall with different degrees of velocity; and as dense, heavy bodies, by their greater momentum (*See number* 42) overcome this resistance more easily than rarer or lighter ones, they will fall with greater velocity.

81. The resistance which the air opposes to the fall of bodies is proportioned to their surface, not to their

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78. What is said of the extent of the power of mutual attraction? 79. What is a vertical or plumb line? How are these lines situated with regard to the earth's surface? Where will these lines meet, if prolonged? Why are not two lines suspended by weights parallel? Are not a pair of scales, hanging perpendicular to the earth, parallel? Why? Why do they appear parallel? Can any two bodies fall to the earth in parallel lines? 80. What is the reason that all bodies, at equal distances from the earth, do not fall in the same space of time? What bodies fall with the greatest velocity? 81. To what is the resistance of the air, in falling bodies, proportioned?

weight. Heavy bodies can be made to float in the air, instead of falling immediately to the ground, by making the extent of their surface counterbalance their weight. Thus gold, which is one of the heaviest of all substances, when spread out into thin leaf, is not attracted by gravity with sufficient force, to overcome the resistance of the air; it therefore floats, as it were, in the air, and falls slowly.

82. All substances of whatever nature are equally influenced by gravity, in exact proportion to their density. Even air itself, light as it seems, is subject to this attraction. The air extends to a height of more than forty-five miles above the surface of the earth. The pressure of the upper parts of the atmosphere on those beneath, renders the air near the surface of the earth much more dense than that in the upper regions. This pressure is caused by the attraction of the earth, or the weight of the air above; and it would cause the air to fall like other bodies completely to the earth; were it not for the elasticity (*See No.* 70,) of that portion which is near the surface. The air therefore of which the atmosphere is composed, exists in a state of constant compression, and is heavier near the surface of the earth, and grows lighter as we ascend. Gravity brings the particles together, while elasticity gives them a constant tendency to expand. Gravity thus confines the air to the region of the earth, while elasticity prevents it from falling like other bodies to the ground.

83. Smoke, steam, and all similar substances, are affected by gravity in a similar manner. But as gravity acts on all substances in exact proportion to their density, and the air near the surface of the earth is more dense than smoke, steam, &c., the air and other similar fluids will arrange themselves in obedience to this law, in regular order, according to their different densities. Accordingly as smoke, steam, &c., are less dense than the air near the surface of the

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How can heavy bodies be made to float in the air? Give an example to illustrate this. 82. In what proportion are all substances influenced by gravity? Is air affected by it? How far does the air extend above the surface of the earth? What causes the air to be more dense at the surface of the earth? What causes this pressure? Why does not the air fall to the earth like other bodies? 83. What causes steam and other similar substances to rise? In what proportion does gravity act upon bodies?

earth, they will rise until they reach a portion of the air, of the same density with themselves, where they will remain stationary.

84. The specific gravity of bodies is a term used to express the relative weight of equal portions of different bodies. We know that a portion of lead will weigh more than a portion of wood of the same size. A piece of wood will weigh more than a piece of cork of the same dimensions, and cork will weigh more than a portion of air, smoke or vapor of the same extension. Hence we say that the specific gravity of cork is greater than that of air, the specific gravity of wood is greater than that of cork, and the specific gravity of lead greater than that of wood, &c.

85. From what has now been said with respect to the attraction of gravitation and the specific gravity of bodies, it appears that although the earth attracts all substances, yet this very attraction causes some bodies to rise and others to fall. Those bodies or substances the specific gravity of which is greater than that of air will fall, and those whose specific gravity is less than that of air will rise,—or rather, the air being more strongly attracted will get beneath them, and, thus displacing them, will cause them to rise. For the same reason, cork and other light substances will not sink in water, because the specific gravity of water being greater, the water is more strongly attracted and will be drawn down beneath them. [*For a table of the specific gravity of bodies, see the note under No.* 213.]

86. The principle which causes balloons to rise, is the same which causes the ascent of smoke, steam, &c. The materials of which a balloon is made, are heavier than air, but their extension is greatly increased, and they are filled with an elastic fluid of a different nature, specifically lighter than air, so that on the whole the balloon when thus filled is much lighter than a portion of air of the same size or dimensions, and it will consequently rise.

When will smoke, steam, and other similar substances remain stationary? 84. What is specific gravity? Illustrate this. 85. Does the attraction of the earth cause all bodies to fall? What bodies will fall? What rise? How does the air cause them to rise? Why do not cork and other light bodies sink in water? Explain the principle upon which balloons rise.

87. Gravity, therefore, causes bodies which are lighter than air to ascend, those which are of equal weight with air to remain stationary, and those which are heavier than air to descend; but the rapidity of their descent is affected by the resistance of the air; which resistance is proportioned to the extent of the surface of the falling body.

88. From what is stated in number 80, it appears that as a dense body, such for instance as a piece of metal or money, is more strongly attracted by the earth than a rarer (that is to say, a lighter) one, its momentum will enable it to overcome the resistance of the air more readily, and that it will consequently fall to the ground more quickly than a lighter one. But if the resistance of the air could be removed, they would both fall in precisely the same time. [*This will be illustrated by experiment in connexion with pneumatics.*]

89. It has been stated (*See No.* 73) that the force of gravity is the greatest at the surface of the earth, and decreases both upwards and downwards, but in different degrees. But the diminution of its force at so small a distance as that to which the atmosphere extends is so inconsiderable, compared with the size of the earth, as to be scarcely perceptible. The greatest height ever attained by man in balloons or on the summit of the highest mountains scarcely exceeds a thousandth part of the distance from the centre to the surface of the earth. Although, therefore, it is true that the air near the surface of the earth is more strongly attracted than that in the upper regions of the atmosphere, yet the difference is so exceedingly small, that it is imperceptible. But the weight of the upper air resting upon the lower (*as is stated in No.* 82,) compresses it into smaller volume and thereby increases its density. This increase of its density causes a corresponding increase of its gravity (according to the principle stated in No., 71.)

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87. What effect has gravity on bodies lighter than the air? What effect on bodies of equal weight? What effect on those that are heavier? What affects the rapidity of their descent? To what is the resistance of the air proportioned? 88. Which is more strongly attracted by the earth, a dense or a rare body? What follows from this? How can they be made to fall at the same time? 89. Where is gravity the greatest? Why is not the diminution of it, as we go from the surface of the earth, very apparent? What is the greatest height in the air ever attained byman?

90. The pressure of the atmosphere has been compared to that of a pile of fleeces of wool, in which the lower fleeces are pressed together by the weight of those above. The uppermost fleece, receiving no external pressure, is confined merely by the force of its own gravity.

91. Smoke consists of minute particles of fuel carried up by a current of heated air from the fire below. As heat expands all bodies [*See No.* 60,] it consequently rarefies (that is, expands) air, and renders it lighter than the colder air of the atmosphere. The heated air from the fire, carries up with it vapor and small particles of the combustible materials which are burning in the fire. When this current of hot air is cooled by mixing with the atmosphere, the minute particles of coal or other combustibles fall, and it is this which produces the small black flakes which frequently render the air, and every thing in contact with it so dirty. This is particularly the case in large cities, where bituminous coal is used for fuel.

92. From what has now been stated, it appears that gravitation is the force which occasions the fall of bodies ; cohesion, that which binds the particles of bodies together ; and heat a force which drives them asunder. These *three* powers may be comprehended under *two* names, Attraction and Repulsion.

SECTION IV.

Mechanics, or the Laws of Motion.

[For a definition of Mechanics, see No. 2.]

93. A body is in motion whenever it is changing its situation with regard to a fixed point. Motion therefore is a continued change of place.

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90. To what has the pressure of the atmosphere been compared ? 91. Of what does smoke consist ? What effect has heat upon bodies ? What follows from this ? What produces the small black flakes which frequently float in the air ? 92. What is gravitation ? Cohesion ? Heat ? Under what names may these powers be comprehended ? 93. What is motion ?

94. On account of the inertia [*See No.* 39,] of all matter, a body cannot put itself in motion, nor when it is in motion can it stop itself. The power which puts a body into motion is called *a force*,—and the power which has a tendency to stop or impede motion is called *resistance*. Thus, the stroke of a hammer is the force which drives a nail; the pulling of the horse is the force which draws the carriage. Force, then, is the cause which produces motion. [*See No.* 93.]

95. The motion of a body impelled by a single force is always in a straight line, and in the same direction in which the force acts.

96. The rapidity with which a body moves, or the length of time which it takes to move from one place to another, is called its velocity.

97. The first law of motion is that the velocity of a moving body is always proportional to the force by which it is put in motion; and that what is gained in power is lost in time.

98. The velocity of a moving body is ascertained by the time that it occupies in passing through a given space. The greater the space, and the shorter the time, the greater is the velocity. Thus, if one body goes through six miles in an hour and another through twelve miles in the same time, the velocity of the latter is double that of the former.

99. Velocity is sometimes called absolute, and sometimes relative. Velocity is called absolute when the motion of a body in space is considered without reference to that of other bodies. When, for instance, a horse goes a hundred miles in ten hours, his absolute velocity is ten miles an hour.

100. Velocity is called relative when it is compared with that of another body. Thus, if one horse travels only fifty miles in ten hours, and another one hundred,

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94. Why cannot a body put itself in motion? Why cannot a body stop itself when in motion? What is force? What is resistance? What illustrations are given? 95. When is the motion of a body in a straight line? In what direction will it move? 96. What is meant by velocity? 97. What is the first law of motion? 98. How is the velocity of a moving body ascertained? If one body goes through six miles in an hour, and another twelve, how does the velocity of the last compare with that of the first? 99. What is meant by absolute velocity? Give an example. 100. When is the velocity of a body termed relative?

in the same time, the absolute velocity of the first horse is five miles an hour, and that of the latter is ten miles ; but the relative velocity of the latter is double that of the former.

101. The velocity of a body is measured by the space over which it moves, divided by the time which it employs in the motion. Thus, if a body moves one hundred miles in twenty hours, the velocity is one hundred divided by twenty, that is, five miles an hour.

102. The time employed by a body in motion may be ascertained by dividing the space by the velocity. Thus, if the space be one hundred miles, and the velocity five miles in an hour, the time will be one hundred divided by five, which is twenty hours.

103. The space also may be ascertained by multiplying the velocity by the time. Thus if the velocity be five miles an hour, and the time twenty hours, the space will be twenty multiplied by five, which is one hundred miles.

104. There are four terms applied to motion to express its kind ; namely, uniform, accelerated, retarded, and perpetual motion.

105. Uniform motion is that of a body passing over equal spaces in equal times.

106. Accelerated motion is that in which the velocity continually increases as the body moves.

107. Retarded motion is that in which the velocity decreases as the body moves.

108. Perpetual motion is that which continues either in a uniform, accelerated, or retarded state, without limit.

109. Uniform motion is produced by a force having acted on a body and then ceasing to act. A ball struck by a bat, or a stone thrown from the hand, is, in theory, an instance of uniform motion ; but as the ball in both cases has to encounter the attraction of

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Give an example 101. How is the velocity of a body measured ? Illustrate this. 102. How do you ascertain the time employed by a body in motion ! Illustrate this. 103. How can you ascertain the space ? Illustrate this. 104. How many terms are applied to motion to express its kind ? What are they ? 105. What is uniform motion ? 106. Accelerated ? 107. Retarded ? 108. What is perpetual motion ? 109. How is uniform motion produced ? Why is not a ball struck by a bat, or a stone thrown from the hand, an instance of uniform motion ?

gravity on the one hand, which has a tendency to draw it to the ground, and the resistance of the air on the other, it in fact becomes an instance of retarded motion. But if both the attraction of gravity and the resistance of the air could be entirely removed, it would proceed onwards in a straight line and with a uniform motion forever.

110. Accelerated motion is produced by the continued action of one or more forces. Thus, when a stone falls from a height, the impulse which it receives from gravity would be sufficient to bring it to the ground, with a uniform velocity; namely, sixteen feet every second of time. But the stone while falling at this rate is still acted upon by gravity with an additional force, which continues to impel it during the whole time of its descent.

It is therefore found that during the first second it falls sixteen feet, three times that distance in the next, five times in the third, seven times in the fourth, and so on, regularly increasing its velocity according to the number of seconds consumed in falling. The height of a building, or the depth of a well, may thus be measured by observing the length of time which a stone takes in falling from the top to the bottom.

111. Retarded motion is produced when a body in motion encounters a force operating in an opposite direction from the motion. Thus when a stone is thrown perpendicularly upwards, the force of gravity is continually operating in the opposite direction, and attracting it downwards to the earth. The stone moves upwards slower and slower, until the upward motion ceases, and the body returns with accelerated motion to the earth. It is found that when a body is thrown perpendicularly upwards, it takes the same length of time in ascending, that it takes in descending.

112. Perpetual motion has never yet been produced by art, because gravity ultimately destroys all motion, that human powers can produce. But nature abounds with

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How can it be made an instance? 110. How is accelerated motion produced? Give an instance of accelerated motion. How far does a stone fall the first second of time? The second? Third? Fourth? How can you measure the height of a building, or the depth of a well? 111. How is retarded motion produced? Give an example. How does the time of the ascent and descent of a body thrown perpendicularly, compare? 112. Why cannot perpetual motion be produced?

examples of perpetual motion, as for instance, the motion of the heavenly bodies, described in the science of astronomy.

113. The momentum of a body [*See No.*42] is its degree of motion. In other words, the momentum of a body is the force or power with which a moving body would strike against another body.

114. The momentum of a body may be ascertained, by multiplying* its weight by its velocity.† The quicker a body moves, the greater will be the force with which it will strike against another body; ‡ so that a small, light body may have a greater momentum than a large heavy one, provided its velocity be sufficiently great. For instance, the momentum of an arrow, shot from a bow, is greater than that of a stone thrown from the hand, because its velocity is greater. But the momentum depends not alone on the velocity. On account of the inertia [*See No.* 39] of all matter, the greater the quantity of matter in a moving body, the

* That the momentum is ascertained by *multiplying*, *not by adding* the weight and velocity, is proved by the following reasoning: If two bodies, one of one pound weight, the other of two pounds, have the same velocity, the moving force of the second, or its momentum, is double that of the first. If a third body, also of two pounds, move with three times the velocity of the second, its momentum, as the weights in this case are equal, is three times that of the second. But the momentum of the second is twice that of the first, therefore the momentum of the third is three times this quantity, or six times that of the first. By thus dividing the process, and looking first to the effect of a change of the velocity, and afterwards to that of the change of the weight, it becomes evident that these effects are to be multiplied together.

† The quantity of motion communicated to a body does not affect the duration of the motion. If but little motion is communicated, the body will move slowly. If a great degree is imparted, it will move rapidly. But in both cases the motion will continue until it is destroyed by some external force.

‡ The resistance of the air, as is stated in No. 41, affects the momentum of all bodies. As this resistance is proportioned to the extension of a body, it follows that it affects large bodies more powerfully than small ones of equal weight. In all nice calculations, allowance is made for the resistance of the medium in which bodies are supposed to move.

Give some instances of perpetual motion in nature. 113. What is the momentum of a body? *Notes.*—How can it be proved that the momentum is ascertained by *multiplying, not by adding*? Does the quantity of motion communicated to a body affect the duration of the motion? If but little motion is communicated, how will the body move? If a great degree? How long will the motion continue? Does the resistance of the air affect the momentum of a body? To what is this resistance proportioned? What follows from this? What allowance is made in all nice calculations? 114. How can the momentum of a body be ascertained? How can a light body be made to have a greater momentum than a heavy one? Give an instance of this. Does the momentum depend alone upon the velocity?

greater must be the force to stop it; and of course the greater the force with which it will strike against another body.

115. By the *action* of bodies is meant the effect which they produce upon other bodies. By *reaction* is meant the effect which they receive from the bodies on which they act. Thus, when a body in motion strikes against another body, it acts upon it, or produces action; but it also meets with resistance from the body which is struck, and this resistance is the reaction of the body.

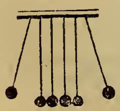
116. Action and re-action are always equal, but in opposite directions.

Experiments to show the mutual action and reaction of bodies, are made with both elastic and non-elastic bodies. [*See No.* 70, and the note connected with it.] Fig. 3 represents two ivory balls, A and B, of equal weight, &c. suspended by threads. If the ball A be drawn a little on one side and then let go, it will strike against the other ball B, and drive it off to a distance equal to that through which the first ball fell; but the motion of A will be stopped, because, when it strikes B it receives in return a blow equal to that which it gave, but in a contrary direction, and its motion is thereby stopped, or, rather, given to B. Therefore, when a body strikes against another, the quantity of motion communicated to the second body is lost by the first; but this loss proceeds, not from the blow given by the striking body, but from the reaction of the body which it struck.

Fig. 3.

Fig. 4 represents six ivory balls, of equal weight, suspended by threads. If the ball A be drawn out of the perpendicular, and let fall against B, it will communicate its motion to B, and receive a reaction from it which will stop its own motion. But the ball B cannot move without moving C, it will therefore communicate the motion which it received from A. to C, and receive from C a reaction which will stop its motion. In like manner the motion and reaction are received by each of the balls, D, E, F; but as there is no ball beyond F to react upon it, F will fly off.

Fig. 4.



N. B. This experiment can be accurately performed by those bodies only which are perfectly elastic.

Fig. 5.

Fig. 5 represents two balls of clay, (which are not elastic) of equal weight, suspended by strings. If the ball D be raised and let fall against E, only part of the motion of D will be destroyed by it, (because the bodies are non-elastic, and the two balls will move on together to *d* and *e*, which are less distant from the vertical line than

115. What is meant by action? Reaction? Illustrate this. 116. How do action and reaction compare? Explain Fig. 3d. Fig. 4th. Fig. 5th.

the ball D was before it fell. Still, however, action and reaction are equal, for the action on E is only enough to make it move through a smaller space, but so much of D's motion is now also destroyed.*

117. It is upon the principle of action and reaction, that birds are enabled to fly. They strike the air with their wings, and the reaction of the air propels them, and they are enabled to rise, fall, or remain stationary at will, by increasing or diminishing the force of the stroke of their wings.†

It is likewise upon the same principle of action and reaction, that fishes swim, or, rather, make their way through the water, namely, by striking the water with their fins.‡

Boats are also propelled by oars on the same principle, and the oars are lifted out of the water, after every stroke, so as completely to prevent any reaction in a backward direction.

118. The word *reflected* means *turned back.* Motion, therefore, which is *turned back* is called *reflected motion.* Thus, when a ball is thrown against a hard wall, it rebounds, or is turned back. This return of the ball is called reflected motion, and it is caused by the reaction of the wall against which it struck. Reflected motion, therefore, is caused by Reaction.

119. As reflected motion is caused by reaction, and reaction is caused by elasticity, it follows that reflected motion is always greater in those bodies which are most elastic. For this reason, a ball filled with air,

* Figs. 3 and 4, as has been explained on the preceding page, show the effect of action and reaction in elastic bodies, and Fig. 5 shows the same effect in non-elastic bodies. When the elasticity of a body is imperfect, an intermediate effect will be produced; that is, the ball which is struck will rise higher than in case of non-elastic bodies, and less so than in that of perfectly elastic bodies; and the striking ball will be retarded more than in the former case, but not stopped completely, as in the latter.; They will, therefore, both move onwards after the blow, but not together, or to the same distance; but in this, as in the preceding cases, the whole quantity of motion destroyed in the striking ball, will be equal to that produced in the ball struck.

† The muscular power of birds is much greater, in proportion to their weight, than that of man. If a man were furnished with wings sufficiently large to enable him to fly, he would not have sufficient strength, or muscular power, to put them in motion.

‡ The power possessed by fishes, of sinking or rising in the water, is greatly assisted by a peculiar apparatus furnished them by nature, called an air-bladder, by the expansion or contraction of which, they rise or fall, on the principle of specific gravity.

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117. Upon what principle do birds fly? Explain how. Upon what principle do fishes swim? Upon what principle do boats move upon the water? Explain how. 118. What does the word reflected mean? What is reflected motion? 119. In what bodies is reflected motion the greatest?

rebounds better than one stuffed with bran or wool, because its elasticity is greater. For the same reason, balls made of Caoutchouc, or India Rubber, will rebound more than those which are made of other substances.

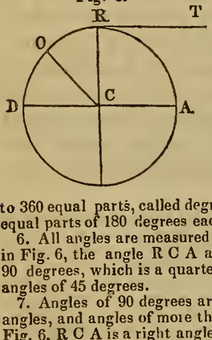
120. The word *incident*, or *incidence*, means *falling upon*, or *directed towards*. Incident motion therefore is motion directed towards any particular object. Reflected motion is the same motion turned back. When a ball strikes against a wall, it is called the incident ball; and when it rebounds from the wall it is called the reflected ball.

121. The angle* of incidence is the angle formed by

* As this book may fall into the hands of some who are unacquainted with the meaning of angle, perpendicular, the divisions of a circle, &c. a few explanations are here subjoined.

1. An angle is the opening made by two lines which meet together in a point. The size of the angle depends upon the opening, and not upon the length of the lines.

Fig. 6.



2. A circle is a perfectly round figure, every part of the outward edge of which is equally distant from a point within, called the centre. [*See Fig.* 6.]

3. The straight lines drawn from the centre to the circumference are called radii. [*The singular number of this word is radius.*] Thus, in Fig. 6, the lines CD, CO, CR, and CA, are radii.

4. The lines drawn through the centre, and terminating in both ends at the circumference, are called diameters. Thus, in the same Figure, D A is a diameter of the circle.

5. The circumference of all circles is divided into 360 equal parts, called degrees. The diameter of a circle divides it into two equal parts of 180 degrees each.

6. All angles are measured by the number of degrees which they contain. Thus in Fig. 6, the angle R C A as it includes one quarter of the circle, is an angle of 90 degrees, which is a quarter of 360. And the angles R C O and O C D are angles of 45 degrees.

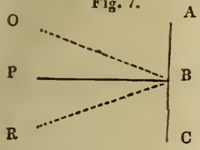
7. Angles of 90 degrees are right angles; angles of less than 90 degrees, acute angles, and angles of more than 90 degrees are called obtuse angles. Thus, in Fig. 6, R C A is a right angle, O C R acute, and O C A obtuse angles.

8. A perpendicular line is a line which makes an angle of 90 degrees on each side of any other line or surface; therefore, it will incline neither to the one side nor to the other. Thus, in Fig. 6, R C is perpendicular to D A.

Give an instance to illustrate this 120. What does the word incident, or incidence mean? What is incident motion? What is reflected motion? What is the ball called that strikes against a wall? When it rebounds? 121. What is the angle of incidence? (*Note*—1. What is an angle? Upon what does the size of an angle depend? 2. What is a circle? 3. What are radii? What lines in Fig. 6 are radii? 4. What are diameters? In Fig. 6, what line is the diameter? 5. How is the circumference of all circles divided? Into how many parts does the diameter of a circle divide it? 6. How are all angles measured? Illustrate this by Fig. 6. 7. How many degrees do right angles contain? Acute? Obtuse? Illustrate these angles by Fig. 6. 8. What is a perpendicular line? What line is perpendicular in Fig. 6?

the line which the incident body makes in its passage towards any object, and a line perpendicular to the surface of the object. Thus, in Fig. 7, the line A B C represents a wall, and P B a line perpendicular to its surface. O is a ball moving in the direction of the dotted line, O B. The angle O B P is the angle of incidence.

Fig. 7.



122. The angle of reflection, is the angle formed by the perpendicular, and the line made by the reflected body in its passage, from the surface against which it struck. Thus, in Figure 7th, the angle P B R is the angle of reflection.

123. The angles of incidence and reflection are always equal to one another. Thus, in Figure 7th, the angle of incidence, O B P and the angle of reflection P B R are equal to one another; that is, they contain an equal number of degrees.

124. From what has now been stated with regard to the angles of incidence and reflection, it follows, that when a ball is thrown perpendicularly against an object, it will return in the same direction; but if it is thrown obliquely, it will return obliquely on the opposite side of the perpendicular. The more obliquely the ball is thrown, the more obliquely it will rebound.*

9. The tangent of a circle is a line which touches the circumference, without cutting it when lengthened at either end. Thus, in Fig. 6 the line T is a tangent.

10. A square is a figure having four equal sides, and four equal angles. These will always be right angles. [*See Fig.* 8th.

11. A parallelogram is a figure whose opposite sides are equal and parallel. [*See Figs.* 9 *and* 10.] A square is also a parallelogram.

12. A rectangle is a parallelogram whose angles are right angles.

13. The diagonal of a square, of a parallelogram, or a rectangle, is a line drawn through either of them, and terminating at the opposite angles. Thus, in Figs. 8, 9 and 10, the line AC is the diagonal of the square, parallelogram, or rectangle.

* It is from a knowledge of these facts that skill is acquired in many different sorts of games, as Billiards, Bagatelle, &c.

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9 What is a tangent? What line is a tangent in Fig. 6? 10. What is a square? 11. What is a parallelogram? 12. A rectangle? 13. What is a diagonal? What lines are diagonal in Figs. 8, 9 and 10?) 121. Explain the angle of incidence by the figure. 122. What is the angle of reflection? Illustrate this by Fig. 7. 123. How do the angles of incidence and reflection compare with each other? Illustrate this by Fig. 7. 124. What follows from what has been stated with regard to the angles of incidence and reflection.

SECTION III.

Mechanics or the Laws of Motion continued.—Compound Motion.

125. Compound motion is that which is caused by the operation of two or more forces at the same time.

When a body is struck by two equal forces in opposite directions it will remain at rest.

126. A body struck by two forces in different directions, will move in a line between them. This line will be the diagonal of a parallelogram, having for its side the lines through which the body would pass, if actuated by each of the forces separately.

Illustration 1st. Fig. 8 represents a ball struck by the two equal forces, X and Y. In this figure, the forces are inclined to each other at an angle of 90 degrees, or a right angle. The force X would send it from C to B, and the force Y would send it from C to D. As it cannot obey both, it will go between them to A, and the line C A, through which it passes, represents the diagonal of the square, A B C D. The time occupied in its passage from C to A will be the same as the force X would require to send it to B, and the force Y to send it to D.

Fig. 8.

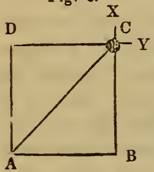

Illustration 2d. If the two forces acting on a body are unequal, but still operate at right angles to each other, the body will move from C to A as represented in Fig. 9; in which it is to be observed that the force Y is as much greater than the force X, as the length of the side A B of the rectangle A B C D, exceeds the length of the side C B.

Fig. 9.

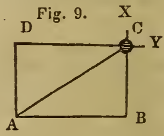

Fig. 10.

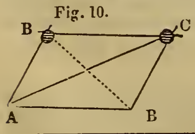

Illustration 3d. When two forces operate in the direction of an acute angle, [*See Fig.* 10,] the body will move, as represented by C A in the parallelogram A B C D.

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125. What is compound motion? In what direction will a body, struck by two equal forces in opposite directions, move? 126. In different directions? What is this line called? Illustrate these first, by Fig. 8. which represents a ball struck by two equal forces in different directions. Second, by Fig. 9, which represents a ball struck by two unequal forces, acting at right angles. Third, by Fig. 10, where the forces operate in the direction of an acute angle.

Illustration 4th. If the forces operate in the direction of an obtuse angle, the body will move as represented by D B in the same figure.

127. Circular motion, is motion in a circular direction, and is caused by two forces operating at the same time, by one of which it is projected forward in a straight line, while by the other it is confined to a fixed point.

Illustration. The whirling of a ball, fastened to a string held by the hand, is an instance of circular motion. The ball is actuated by two forces, namely, the force of projection, and the string which confines it to the hand. The two forces act at right angles to each other, and, (*according to No.*126,) the ball will move in the diagonal of a parallelogram. But, as the force which confines it to the hand only keeps it within a certain distance, without drawing it nearer to the hand, the motion of the ball will be through the diagonals of an infinite number of parallelograms, formed by every part of the circle.

128. The centre of motion is the point to which a revolving body is confined. But when the body is not of a size or shape to allow every point to revolve in the same plane, the line round which it revolves is called the axis of motion. The axle of a wheel is the axis of the motion of the wheel. The centre or axis of motion is not always in the middle of a body.

129. The force which confines a body to the centre round which it moves, is called the Centripetal* force. The force which compels a body to fly off from the centre, is called the Centrifugal* force. These are called central forces.

130. If the centrifugal force of a revolving body be destroyed, the body will immediately approach the centre which attracts it; but if the centripetal force be destroyed, the body will fly off in the direction of a tangent of the circle which it described in its motion. [*See Fig.* 6.]

* The word *centripetal* means seeking the centre, and *centrifugal* means flying from the centre. The centrifugal force is sometimes called the projectile force. In circular motion, these two forces constantly balance each other; otherwise the revolving body will either approach the centre or recede from it, according as the centripetal or centrifugal force is the stronger.

Fourth, by Fig. 10, where the forces operate in the direction of an obtuse angle. 127. What is circular motion? How is it caused? Illustrate this. 128. What is the centre of motion? What is the axis of motion? 129. What is the centripetal force? What is the centrifugal force? What are the centripetal and centrifugal forces called? 130. What would be the consequence if the centrifugal and centripetal forces were destroyed, or did not balance each other? What is the meaning of the words centripetal and centrifugal?

Illustration. If a mop filled with water is turned swiftly round by the handle, the threads which compose the head will fly off from the centre; but being confined to it at one end, they cannot part from it; whilst the water they contain, being unconfined, is thrown off in straight lines. [*See No.* 137.]

131. The middle point of a body is its centre of magnitude.

132. The centre of gravity is the point about which all the parts balance each other. The centre of gravity, therefore, is not in the same spot with the centre of magnitude, unless the body is of the same density.

133. The centre of motion is the point round which all the parts of a body move. But the centre of motion is generally supposed to be at rest. Thus the axis of a spinning top is stationary, while every other part is in motion around it. The axis of motion and the centre of motion are terms which relate only to circular motion.

134. Those parts of a body which are farthest from the centre of motion, move with the greatest velocity; and the velocity of all the parts diminishes, as their distance from the axis of motion diminishes.

Illustration 1*st.* Fig. 11 represents the vanes of a windmill. The circles denote the paths in which the different parts of the vanes move. M is the centre or axis of motion around which all the parts revolve. The outer part revolves in the circle D E F G, another part revovles in the circle H I J K, and the inner part in the circle L N O P. Consequently, as they all revolve around M in the same time. The velocity of the parts which revolve in the outer circles D E F G and H I J K is as much greater than the velocity of the part which revolves in the inner circle, L N O P, as the outer circles are larger than the inner ones.

Fig. 11.

As the earth revolves round its axis, it follows, from the preceding illustration, that the portions of the earth which move most rapidly are nearest to the equator, and that the nearer any portion of the earth is to the poles, the slower will be its motion.

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131. What is the centre of magnitude? 132. What is the centre of gravity? When are the centres of magnitude and gravity in the same spot? 133. What is the centre of motion? Is the centre of motion supposed to be at rest, or does it move? To what do the terms centre of motion and axis of motion relate? 134. What parts of a body move with the greatest velocity? In what proportion does the velocity of all the parts diminish? What does Fig. 11 represent? What follows with regard to the motion of the earth, from the illustration of Fig. 11?

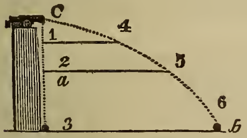
135. Motion, either in a circle or ellipsis, or any other curve line, must be the result of the action of two forces; for, the impulse of one single force always produces motion in a right or straight line.

136. A ball thrown in a horizontal direction is always influenced by three forces; namely, first, the force of projection, (which gives it the horizontal direction;) second, the resistance of the air through which it passes, which diminishes its velocity, without changing its direction; and third, the force of gravity which finally brings it to the ground.

137. The power of gravity, and the resistance of the air, being always greater than any force of projection we can give a body, the force of projection is gradually overcome, and the body brought to the ground. The stronger the projectile force, the farther the body will go before it falls. For this reason, a shot fired from a cannon will go much farther than a stone thrown from the hand.*

Illustration. Fig. 12 represents a cannon, loaded with a ball, and placed on the top of a tower, at such a height as to require just three seconds for another ball to descend perpendicularly. Now suppose the cannon to be fired in a horizontal direction, and at the same instant the other ball to be dropped toward the ground. They will both reach the horizontal line at the base of the tower at the same instant. In this figure *a* represents the perpendicular line of the falling ball. C *b* the curvilinear path

Fig. 12



* The action of gravity being always the same, the shape of the curve of every projectile (*See No.* 39.) depends on the velocity of its motion. But, whether this velocity be great or small, the moving booy, if thrown horizontally from the same elevation, will reach the ground at the same instant. Thus a ball from a cannon, with a charge sufficient to throw it half a mile, will reach the ground at the same instant of time that it would, had the charge been sufficient to throw it one, two, or six miles, from the same elevation. The distance to which a ball will be projected, will depend entirely on the force with which it is thrown, or on the velocity of its motion. If it moves slowly, the distance will be short—if more rapidly, the space passed over in the same time will be greater; but in both cases the descent of the ball towards the earth, in the same time, will be the same number of feet, whether it moves fast or slow, or even whether it move forward at all, or not.

135. Of what is motion in a circle or curve line always the result? Why? 136. How many forces act upon a ball thrown in a horizontal direction? What are they? 137 Why do bodies fall to the ground? Why do some bodies go farther than others before they fall? What does Fig. 12 represent? *Note.*—Upon what does the shape of the curve of every projectile depend? Does the time of the descent, if thrown horizontally, depend upon the velocity? Illustrate this. Upon what does the distance, to which a ball may be projected, depend?

of the projected ball, 3 the horizontal line at the base of the tower. During the first second of time, the falling ball reaches 1, the next second 2, and at the end of the third second it strikes the ground. Meantime, that projected from the cannon, moves forward with such velocity, as to reach 4 at the same time that the falling ball reaches 1. But the projected ball falls downward exactly as fast as the other, since it meets the line 1 4, which is parallel to the horizon, at the same instant. During the next second the ball from the cannon reaches 5, while the other falls to 2, both having descended through the same space. During the third second the projected ball will have spent nearly its whole force, and therefore its downward motion will be greater while the motion forward will be less than before.

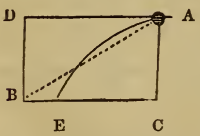
From hence it appears that the horizontal motion does not in the least interfere with the action or the effect of gravity; but that the projectile descends with the same rapidity while moving forward that it would if its motion was perpendicular to the horizon. This is the necessary result of the action of two forces, according to the principle stated in No. 126.

138. A projectile is any body thrown into the air, as a rocket, a ball from a gun, or a stone from the hand.

139. Projectiles form a curve line in their descent. The force of projection being strongest, when they are first impelled, is constantly weakened by the resistance of the air, and the force of gravity, as the body proceeds. The direction, therefore, of their motion is gradually changed from a horizontal to a perpendicular direction.

Illustration. In Fig. 13 the force of projection would carry a ball from A to D, while gravity would bring it to C. If these two forces alone prevailed, the ball would proceed in the dotted line to B (according to the principle stated in number 126.) But as the resistance of the air operates in direct opposition to the force of projection instead of reaching the ground at B, it will fall somewhere about E.

Fig. 13.



It is calculated that the resistance of the air to a cannon ball of two pounds weight, with the velocity of two thousand feet in a second, is more than equivalent to sixty times the weight of the ball.

140. When a body is thrown upward *obliquely*, its

What follows from this? 138. What is a projectile? 139. What line do projectiles form in their descent? Why is the direction of their motion gradually changed from a horizontal to a perpendicular direction? Illustrate this by Fig. 13. How great is the resistance of the air calculated to be to a canon ball of two pounds weight, with the velocity of 2000 feet in a second? 140. In what direction will a body move, when it is thrown upwards obliquely?

course will be in the direction of a curve-line, called a *parabola*,* [*See Fig.* 14.] but when it is thrown *perpendicularly* upwards, it will descend perpendicularly, because the force of projection and that of gravity are in the same line of direction.

Fig. 14.

141. The random of a projectile is the horizontal distance from the place whence it is thrown, to the

* The science of *gunnery* is founded upon the laws relating to projectiles. The force of gunpowder is accurately ascertained, and calculations are predicated upon these principles, which enable the engineer to direct his guns in such a manner as to cause the fall of the shot or shells in the very spot where he intends. The knowledge of this science saves an immense expenditure of ammunition, which would otherwise be idly wasted without producing any effect. In attacks upon towns and fortifications, the skilful engineer knows the means he has in his power, and can calculate, with great precision, their effects. It is in this way that the art of war has been elevated into a science; and much is made to depend upon skill, which, previous to the knowledge of these principles, depended entirely upon physical power. It is likewise by the same means that wars are rendered much less sanguinary in modern times. The force with which balls are thrown by gunpowder is measured by an instrument called the *Ballistic pendulum.* It consists of a large stock of wood suspended by a rod in the manner of a pendulum. Into this block the balls are fired, and to it they communicate their own motion. Now the weight of the block, and that of the ball being known, and the motion or velocity of the block being determined by machinery, or by observation, the elements are obtained by which the velocity of the ball may be found; for, *the weight of the ball is to the weight of the block as the velocity of the block is to the velocity of the ball.* By this simple apparatus, many facts relative to the art of gunnery may be known. If the ball be fired at different distances, from the same gun, it will be seen how much resistance the atmosphere opposes to its force at such distances. Rifles and guns of smooth bores may be tested, as well as the various charges of powder best adapted to different distances and different guns. These, and a great variety of other experiments, useful to the practical gunner, or sportsman, may be made by this simple means.

With respect to the velocity of balls impelled by gunpowder, it has been found that, with a common charge, from a musket, this is about 1650 feet per second, when first discharged. The utmost velocity that can be given to a cannon ball, is 2000 feet per second; and this only at the moment of its leaving the gun.

In order to increase the velocity from 1650 to 2000 feet, one half more powder is required; and even then, at a long shot, no advantage is gained; since, at the distance of 500 yards, the greatest velocity that can be obtained is only 1200 or 1300 feet per second. Great charges of powder are therefore not only useless, but dangerous; for, though they give little additional force to the ball, they hazard the lives of many by their bursting power.

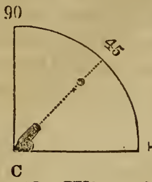
Experiment has also shown, that, although long guns give a greater velocity to the shot than short ones, still, that on the whole, short ones are preferable; and, accordingly, armed ships are now almost invariably furnished with short guns, called carronades.

The length of sporting guns has also been greatly reduced, of late years. Formerly, the barrels were from four to six feet in length; but the best fowling pieces of the present day have barrels of two feet, or two and a half, only, in length. Guns of about this length are now universally employed for such game as woodcocks, partridges, grouse, and such birds as are taken on the wing, with the exceptions of ducks and wild geese, which require longer and heavier guns.

When will a ball descend in the same direction in which it ascended? Why?
141. What is the random of a projectile?

place where it strikes. The greatest random takes place at an angle of 45 degrees—that is, when a gun is pointed at this angle with the horizon, the ball is thrown to the greatest distance. Fig. 15 represents a gun or a carronade, from which a ball is thrown at an angle of 45 degrees with the horizon.

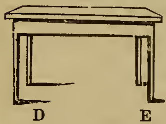
Fig. 15.



142. When the centre of gravity of a body (*See No.* 132) is not supported, the body will fall.

143. The base of a body is its lowest side. The base of a body standing on wheels or legs, is represented by lines drawn from the lowest part of one wheel or leg, to the lowest part of the other wheel or leg. Thus, in Figures 16 and 17, D E represents the base of the wagon and of the table.

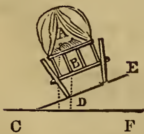
Fig. 16.



144. Whenever a line drawn from the centre of gravity and perpendicular to the horizon falls within the base of a body, the body will stand, but when that line falls outside of the base, the body will fall or be overset. This line is called the line of direction, because it is the line which the centre of gravity would describe, if the body were suffered to fall.

Illustration. Fig. 17 represents a loaded wagon on the declivity of a hill. The line C F represents the horizon. D E the base of the wagon. If the wagon be loaded in such a manner that the centre of gravity is at B, the perpendicular B D falls within the base, and the wagon will stand. But if the load be altered so that the centre of gravity is raised to A, the perpendicular AC will fall outside of the base, and the wagon will be overset. From this it follows that a wagon, or any carriage, will be most firmly supported when the centre of gravity falls exactly between the wheels; and that is the case on a level road. The centre of gravity, in the human body, is between the hips, and the base is the feet and the space between them.

Fig. 17.



At what angle does the greatest random take place? 142. When will a body fall? What is the base of a body? In Fig. 16 and 17, what represents the base? 144. When will a body stand? When will it fall? Illustrate this by Fig. 17. What follows from this? Where is the centre of gravity in the human body? Where is the base?

So long as we stand uprightly, the line of direction falls within this base. When we lean on one side, the centre of gravity, not being supported, we no longer stand firmly.

A rope-dancer performs all his feats of agility by dexterously supporting the centre of gravity. For this purpose he carries a heavy pole in his hands, which he shifts from side to side as he alters his position, in order to throw the weight to the side which is deficient; and thus, by changing the situation of the centre of gravity, he keeps the line of direction within the base, and he will not fall.*

145. A spherical body will roll down a slope, because the centre of gravity is not supported.†

146. When a body is of uniform density, the centre of gravity is in the same point; when one part of the body is composed of heavier materials than another part, the centre of gravity, (being the centre of the weight of the body,) no longer corresponds with the centre of magnitude. Thus the centre of gravity of a cylinder plugged with lead, is not in the same spot as the centre of magnitude. Bodies, therefore, consisting of but one kind of substance, as wood, stone, or lead, and whose densities are consequently uniform, must stand more firmly, and be more difficult to overset, than bodies composed of a variety of substances, of different densities, which may throw the centre of gravity on one side.

* The shepherds in the south of France afford an interesting instance of the application of the art of balancing to the common business of life. These men walk on stilts from three to four feet high, and their children, when quite young, are taught to practise the same art. By means of these odd additions to the length of the leg, their feet are kept out of the water, or the heated sand, and they are, also, enabled to see their sheep at a greater distance. They use these stilts with great skill and care, and run, jump, and even dance on them with great ease.

† A cylinder can be made to roll up a slope, by plugging one side of it with lead; the body being no longer of a uniform density, the centre of gravity is removed from the middle of the body to some point in the lead, as that substance is much heavier than wood. Now, in order that the cylinder may roll down the plane, as it is here situated, the centre of gravity must rise, which is impossible; the centre of gravity must always descend in moving, and will descend by the nearest and readiest means, which will be by forcing the cylinder up the slope, until the centre of gravity is supported, and then it stops.

How is it that rope-dancers perform their feats of agility? 145. Why do spherical bodies roll down slopes? How can a cylinder be made to roll up a slope? How does this affect it? 146. Where is the centre of gravity in a body of uniform density? Do the centre of gravity and the centre of magnitude correspond when one part of a body is composed of heavier materials than another? What bodies must stand more firmly than others? Why?

147. Bodies that have a narrow base are easily overset; for if they are the least inclined, the line of direction will fall outside of the base, and their centre will not be supported.*

148. The broader the base, and the nearer the centre of gravity to the ground, the stronger will be the edifice.

For this reason a pyramid, as it has a broad base and but little elevation, is the firmest and most durable of all structures.

149. When two bodies are fastened together, they are to be considered as forming but one body, and have but one centre of gravity. If the two bodies are of equal weight, the centre of gravity is in the middle of the line which unites them. But if one be heavier than the other, the centre of gravity is as much nearer to the centre of the heavy one than to the light one, as the heavy exceeds the light one in weight.

Illustration. Fig. 18 represents a rod or pole with an equal weight fastened at each end: the centre of gravity is at A, the middle of the rod, and whatever supports this centre will support both the bodies and the pole.

Fig. 18.

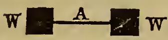


Fig. 19.

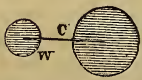


Fig. 19 represents a rod or pole with an unequal weight at each end. The centre of gravity is at C nearer to the larger body.

Fig. 20 represents a rod or pole with unequal weights at each end, but the larger weight exceeds the less in such a degree that the centre of gravity is within the larger body at C.

Fig. 20.

* A person can carry two pails of water more easily than one, because they balance each other and the centre of gravity remains supported by the feet. But a single pail throws the centre of gravity on one side, and renders it more difficult to support the body.

147. Why do bodies which have a narrow base overturn more easily than those which have broad bases? Why can a person carry two pails of water more easily than one? 148. Why is a pyramid the firmest and most durable of all structures? 149. If two bodies of equal weight are fastened together, where is the centre of gravity? If one be heavier than the other? What does figure 18 represent? Fig. 19? Fig. 20?

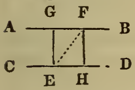
SECTION VI.

Resultant Motion.

150. Resultant motion is the effect, or result of two motions resolved into one.

Illustration. If two men are sailing in two boats, in the same direction, and at the same rate, and one toss an apple to the other, the apple would appear to pass directly across from one to the other, in a line of direction perpendicular to the side of each boat. But its real course is through the air in the diagonal of a parallelogram, formed by the lines representing the course of each boat, and perpendiculars drawn to those lines from the spot where each man stands as the one tosses and the other catches the apple. In Fig. 21

Fig. 21.



the lines A B and C D represent the course of each boat; E is the spot where the man stands who tosses the apple: while the apple is in its passage, the boats have passed from E and G to H and F respectively. But the apple having a motion with the man that would carry it from E to H and likewise a projectile force which would carry it from E to G, cannot obey them both, but will pass through the dotted line E F, which is the diagonal of the parallelogram E G F H, according to the principle in No. 126.

On the principle of resultant motion, if two ships in an engagement are sailing before the wind, at equal rates, the aim of the gunners will be exactly as though they both stood still. But if the gunner fires from a ship standing still, at another under sail, or a sportsman fires at a bird on the wing, each should take his aim a little forward of the mark, because the ship and the bird will pass a little forward while the shot is passing to them.

SECTION VII.

The Pendulum.

151. The Pendulum * consists of a weight, or ball of

* The pendulum was invented by Galileo, a great astronomer of Florence, in the beginning of the seventeenth century. Perceiving that the chandeliers sus-

150. Of what is resultant motion the effect? What illustration is given? Explain by fig. 21. 151. Of what does a Pendulum consist?

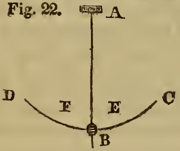
metal, suspended by a rod, and made to swing backwards and forwards.

152. When a pendulum swings, it is said *to vibrate*, and its movements are called *vibrations*. The part of a circle through which it moves, is called its *arc*. The attraction of gravity causes its vibrations.

153. The vibrations of pendulums, of equal length, are very nearly equal, whether they move through a greater or less part of their arcs.

Illustration. In figure 22 A B represents a pendulum. D E F C the arc in which it vibrates. If the pendulum be raised to E it will return to F, if it be raised to C it will return to D in nearly the same length of time, because that in proportion as the *arc* is more extended, the steeper are its beginnings and endings, and, therefore, the more rapidly will it fall.

Fig. 22.



154. The time occupied in the vibration of a pendulum, depends upon its length. The longer the pendulum, the slower are its vibrations.

155. The length of a pendulum which vibrates sixty times in a minute (or in other words which vibrates seconds) is about 39 inches. But in different parts of the earth this length must be varied. A pendulum to vibrate seconds at the equator must be shorter than one which vibrates seconds at the poles.

pended from the ceiling of a lofty church vibrated long and with great uniformity, as they were moved by the wind or by any accidental disturbance, he was led to inquire into the cause of their motion, and this inquiry led to the invention of the pendulum. From a like apparently inconsiderable circumstance arose the great discovery of the principle of gravitation. During the prevalence of the plague, in the year 1665, Sir Isaac Newton retired into the country to avoid the contagion. Sitting in his orchard, one day, he observed an apple fall from a tree. His inquisitive mind was immediately led to consider the cause which brought the apple to the ground, and the result of his inquiry was the discovery of that grand principle of gravitation (*See Nos.*71, 72) which may be considered as the first and most important law of material nature. Thus, out of what had been before the eyes of men, in one shape or another, from the creation of the world, did these philosophers bring the most important results.

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152. When is a pendulum said to vibrate? What are its movements called? What is meant by its arc? What causes its vibrations? 153. How do the vibrations of pendulums of equal length compare? Illustrate by fig. twenty-two. By whom was the pendulum invented? What led him to the discovery? By whom was the principle of gravitation discovered? What led him to the discovery? 154. Upon what does the time of the vibrations of a pendulum depend? 155. What is the length of a pendulum which vibrates sixty times in a minute? Do different situations affect the vibrations? How can a pendulum which vibrates seconds at the equator be made to vibrate seconds at the poles?

156. A clock is regulated by lengthening or shortening the pendulum. By lengthening the pendulum the clock is made to go slower, by shortening it, it will go faster. The pendulum of a clock is made longer or shorter, by means of a screw beneath the weight or ball of the pendulum. The clock itself is nothing more than a pendulum connected with wheel-work, so as to record the number of vibrations. A weight is attached in order to counteract the retarding effects of friction, and the resistance of the air. The wheels show how many swings or beats of the pendulum, have taken place in a given time, because at every beat, the tooth of a wheel is allowed to pass. Now if this wheel has sixty teeth, it will turn round once in sixty vibrations of the pendulum, or in sixty seconds, and a hand fixed on the axis of the wheel projecting through the dial plate will be the second hand of the clock. Other wheels are so connected with the first, and the number of teeth in them so proportioned, that the second wheel turns sixty times slower than the first, and to this is attached the minute hand; and the third wheel moving twelve times slower than the second, carries the hour hand. On account of the expansion of the pendulum by heat, and its contraction by cold, clocks go slower in summer than in winter, because the pendulum is thereby lengthened at that season.

A watch differs from a clock, in having a vibrating wheel instead of a pendulum. This wheel is moved by a spring called the *hair spring*. The place of the weight is supplied by another larger spring called the *main spring*.

SECTION VIII.

The Mechanical Powers.

157. The mechanical powers are certain contrivances

156. How is a clock regulated? What effect has the lengthening of it? The shortening? What is a clock? Of what use is the weight? What do the wheels show? Why do clocks go slower in summer than in winter? How does a watch differ from a clock? 157. What are the mechanical powers?

designed to increase, to diminish, or to alter the direction of any force.

158. There are five things which are to be considered, in order to understand the power of a machine,* Namely: First, The power that acts—Secondly, The resistance which is to be overcome by the powers—Thirdly, The centre of motion, or as it is sometimes called, The fulcrum, (which means a prop or support) Fourthly, The respective velocities of the power and the resistance; and Fifthly, The instruments employed in the construction of the machine.

Illustration. The power that acts is the muscular strength of men, or animals, the weight and momentum of solid bodies, the elastic force of steam, springs, the pressure of the air, &c.

The resistance to be overcome is the attraction of gravity, or of cohesion, the inertness of matter &c.

The centre of motion or the fulcrum, is the point about which all the parts of the body move.

The velocity, as has already been explained, is represented by the time occupied in producing a certain effect.

The instruments are the mechanical powers which enter into the construction of the machine.

159. There are six mechanical powers, namely, the Lever, the Pulley, the Wheel and Axle, the Inclined Plane, the Wedge, and the Screw.

160. The Lever† is an inflexible‡ bar, movable on a fulcrum or prop.

161. There are three kinds of levers, called the first,

* In order to produce any effect by mechanical means, it is necessary that the power employed be greater than the resistance which is to be overcome. Thus, for instance, if the weight of a loaded wagon is greater than the strength of the horses employed to draw it, they will not be able to move it.

† The Lever is made in a great variety of forms, and of many different materials.

‡ By an *inflexible* bar is meant one which will not bend. The fulcrum or prop is, likewise, constructed in a variety of ways. Sometimes it is merely a stone on which a lever in the form of a crow-bar rests. Sometimes it is a pin passing through the lever, &c.

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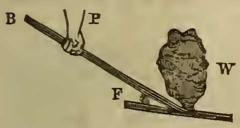
158. How many things are to be considered in order to understand the power of a machine? What is the first? Second? Third? Fourth? Fifth? What is the power that acts? What is the resistance to be overcome? What is the fulcrum? What is the velocity? What is necessary in order to produce any effect by mechanical powers? What illustration of this is given? 159. How many mechanical powers are there? What are they? 160. What is a lever? 161. How many kinds of levers are there? How do they differ?

second, and third kinds, according to the respective position of the fulcrum, the power and the weight.

162. In a lever of the first kind, the weight is at one end, the power at the other, and the fulcrum between them.

Illustration. Fig. 23 represents a simple lever of the first kind, resting on the fulcrum F, and moveable upon it. W is the weight (or heavy stone) to be moved, and P is the power, (or hand) which moves it. The advantage gained in the use of this kind of lever is in proportion as the distance of the power from the fulcrum exceeds that of the weight from the fulcrum. Thus, in this figure, if the distance between P and F be double that between W and F, then a man by the exertion of a force of 100 pounds with the lever can move a weight of 200 lbs. From this it follows that the nearer the power is applied to the end of the lever most remote from the fulcrum the greater is the advantage gained. Thus, in the same figure, a greater weight can be moved by the same power when applied at B than when it is exerted at P.*

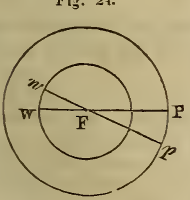
Fig. 23.



A balance or pair of scales is a lever of the first kind, with equal arms. Steelyards, scissors, pincers, snuffers, and a poker used for stirring the fire, are all levers of the first kind. The longer the handles of scissors, pincers, &c., and the shorter the points, the more easily are they used.

*It is a fundamental principal in mechanics that what is gained in power is lost in time. [*See No.* 97.] To illustrate this principle, (Fig. 24,) W represents the weight, F the fulcrum, P the power and the bar, W F P the lever. To raise the weight W to *w*, the power P must descend to *p*. But as the radius of the circle in which the power P moves is double that of the radius of the circle in which the weight W moves, the arc P *p* is double the arc W *w*; or, in other words, the distance P *p* is double the distance of W *w*. Now, as these distances are traversed in the same time by the power and the weight, respectively, it follows that the velocity of the power must be double the velocity of the weight; that is, the power must move at the rate of two feet in a second, in order to move the weight one foot in the same time.

Fig. 24.



This principle applies not only to the lever, but to all the mechanical powers, and to all machines constructed on mechanical principles

When two weights are equal, and the fulcrum is placed exactly in the centre of

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162. What is a lever of the first kind? What figure illustrates this? Explain it by the figure? To what is the advantage, gained by this lever, proportional? What follows from this? What is meant by an inflexible bar? What is a fundamental principle in mechanics? Illustrate this by the figure? Does this principle apply to all the mechanical powers? When two weights are equal where is the fulcrum? How must the fulcrum and power be placed to make the lever act as a mechanical power? Upon what does the force of the lever depend? Give some examples of levers of the first kind.

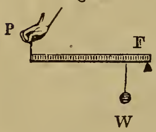
Fig. 25.

A hammer-lever differs only in form from levers of the first kind. A compound lever consists of several levers so arranged that the shorter arm of one may act on the longer arm of the other. (*See fig.* 25.)

163. In a lever of the second kind the fulcrum is at one end, the power at the other, and the weight between them.

Illustration. Fig. 26 represents a lever of the second kind. F is the fulcrum, P the power, and W the weight. The advantage gained by a lever of this kind is in proportion as the distance of the power from the fulcrum exceeds that of the weight from the fulcrum. Thus as this figure of the distance from P to F is four times the distance from W to F, then a power of one pound at P will balance a weight of four pounds at W.

Fig. 26.



This kind of lever explains the manner in which two persons, carrying a heavy burthen, (as, for instance, a cask upon a pole,) may be made to bear unequal portions of it, by placing it nearer to the one than the other.

Two horses, also, may be made to draw unequal portions of a load by dividing the beam attached to the carriage in such a manner that the weaker horse may draw upon the longer end of the beam.

Oars, rudders of ships, doors turning on hinges, and cutting-knives, which are fixed at one end, are constructed upon the principle of levers of the second kind.*

164. In a lever of the third kind, the fulcrum is at one end, the weight at the other, and the power is applied between them.

the lever between them, they will mutually balance each other; or, in other words, the centre of gravity being supported, neither of the weights will sink.

To make the lever act as a mechanical power, the fulcrum must be placed near the weight to be moved, and the power or hand at the greater distance from it. The force of the lever, therefore, depends on its length, together with the power applied, and the distance of the weight from the fulcrum.

* It is on the same principle that in raising a window the hand should be applied to the middle of the sash, it will then be easily rai ed; whereas, if the hand be applied nearer to one side than the other, the centre of gravity being unsupported, will cause the farther side to bear against the frame, and obstruct its free motion.

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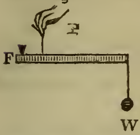
163. What is a lever of the second kind? What figure illustrates this? To what is the advantage gained, by this lever, proportional? Give some examples of levers of the second kind. 164. What is a lever of the third kind?

In levers of this kind the power must always exceed the weight, in the same proportion as the distance of the weight from the fulcrum exceeds that of the power from the fulcrum.

Fig. 27, F is the fulcrum, W the weight, and P the power between the fulcrum and the weight; and the power must exceed the weight in the same proportion that the distance between W and F exceeds the distance between P and F.

Fig. 27.



A ladder which is to be raised by the strength of a man's arms, represents a lever of this kind, where the fulcrum is that end which is fixed against the wall, or upon which a man stands, the weight may be considered as at the top part of the ladder, and the power is the strength applied to the rearing of it.

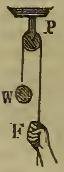
The bones of a man's arm, and most of the movable bones of animals, are levers of the third kind. But the loss of power in the limbs of animals is compensated by the beauty and compactness of the limbs. The wheels, in clock and watchwork, and in various kinds of machinery, may be considered as levers of this kind, when the power that moves them acts on the pinion, near the centre of motion, and the resistance to be overcome acts on the teeth at the circumference. But here the advantage gained is the change of slow into rapid motion. The sails of vessels are constructed on the principal of the lever.

165. The pulley is a small wheel turning on an axis, with a string or rope in a groove running around it.

166. There are two kinds of pulleys, the fixed and the movable. The fixed pulley is a pulley fastened to the wall or to a beam, and is used only for changing the direction of motion.

Illustration. Fig. 28 represents a fixed pulley. P is a small wheel turning on its axis, with a string running round it in a groove. W is a weight to be raised. F is the force or power applied. It is evident that by pulling the string at F the weight must rise just as much as the string is drawn down. As, therefore, the velocity of the weight and the power is precisely the same, it is manifest that they balance each other, and that no mechanical advantage is gained. [*See No.* 97.] But the pulley is very useful for changing the direction of motion. If, for instance, we wish to raise a weight to the top of a high building, it can be done with the assistance of a fixed pulley, by a man standing below.* A curtain or a

Fig. 28.



* The fixed pulley operates on the same principle as a lever of the first kind with equal arms, where the fulcrum being in the centre of gravity, the power and the weight are equally distant from it, and no advantage is gained.

In what proportion must the power exceed the weight in this lever? Explain Fig. twenty-sixth. Give some examples of levers of the third kind. 165. What is a pulley? 166. How many kinds of pulleys are there? What are they? What is a fixed pulley? Explain Fig. twenty seventh. What advantage is gained by this pulley? What is the use of this pulley. Upon what principle does the fixed pulley operate?

sail, also, can be raised by means of the fixed pulley, without ascending with it, by drawing down the string connected with it.

167. The movable pulley differs from the fixed pulley by being attached to the weight; it therefore rises and falls with the weight.

Illustration. Fig. 29 represents a moveable pulley, with the weight W attached to it by a hook below. One end of the rope is fastened at F; and as the power P draws the weight upwards the pulley rises with the weight. Now, in order to raise the weight one inch, it is evident that both sides of the string must be shortened, in order to do which the power P must pass over two inches. As the velocity of the power is double that of the weight, it follows (*by number* 97) that a power of one pound will balance a weight on the moveable pulley of two pounds. From which it appears that—

Fig. 29.

168. The power gained by the use of pulleys is ascertained by multiplying the number of movable pulleys by 2.

Illustration. A weight of 72 pounds may be balanced by a power of 9 pounds with four pulleys; by a power of 18 pounds with two pulleys; or by a power of 36 pounds with one pulley. But in each case the space passed over by the power must be double the space passed over by the weight, multiplied by the number of movable pulleys. That is, to raise the weight one foot, with one pulley, the power must pass over (double of one foot, the space passed over by the weight multiplied by one, which is equal to) two feet, with two pulleys four feet, with four pulleys eight feet.

Fig. 30 represents a system of fixed and movable pulleys. In the block F, there are four fixed pulleys, and in the block M there are four movable pulleys, all turning on their axes, and rising and falling with the weight W. The movable pulleys are connected with the fixed ones by a string attached to the hook H, passing over the alternate grooves of the pulleys in each block, forming eight cords, and terminating at the power P. Now to raise the weight one foot, it is evident that each of the eight cords must be shortened one foot, and, consequently, that the power P must descend eight times that distance. The power, therefore, must pass over eight times the distance that the weight moves.

Fig. 30.

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167. How does the movable pulley differ from the fixed pulley? Explain Fig. twenty-ninth. 168. How can the power, gained by the use of the movable pulleys, be ascertained? What illustration of this is given? What does Fig. thirty represent?

169. Pulleys act on the same principle with the lever, the deficiency of the strength of the power being compensated by its superior velocity. [*See No.* 97.] Now, as we cannot increase our natural strength, but can increase the velocity of motion, it is evident that we are enabled, by pulleys and other mechanical powers, to reduce the resistance or weight of any body to the level of our strength.

Practical use of Pulleys. Pulleys are used to raise goods into warehouses, and in ships, &c. to draw up the sails. Both kinds of pulleys are in these cases advantageously applied; for the sails are raised up to the masts by the sailors on deck by means of the fixed pulleys, while the labor is facilitated by the mechanical power of the movable ones.

Both fixed and movable pulleys are constructed in a great variety of forms, but the principle on which all kinds are constructed, is the same. What is generally called a *tackle and fall*, or a block and tackle, is nothing more than a pulley. Pulleys have, likewise, lately been attached to the harness of a horse to enable the driver to govern the animal with less exertion of strength.

It may be observed, in relation to the mechanical powers in general, that power is always gained at the expense of time and velocity; that is, the same power which will raise one pound in one minute, will raise two pounds in two minutes, six pounds in six minutes, sixty pounds in sixty minutes, &c.; and that the same quantity of force used to raise two pounds one foot, will raise one pound two feet, &c. And, further, it may be stated that the product of the weight, multiplied by the velocity of the power, will always be equal to the product of the power multiplied by the velocity of the weight. Hence we have the following rule. The power is in the same proportion to the weight as the velocity of the weight is to the velocity of the power.

170. The wheel and axle consists of two wheels, one of which is smaller than the other, revolving together around the same centre of motion. The place of the smaller wheel is generally supplied by a cylinder, which is called the axle. A cylinder is a round body with flat ends.

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169. Upon what principle do pulleys act? What advantage is gained by the use of pulleys and other mechanical powers? What are some of the practical uses of the pulley? What is a tackle and fall? Is there any time or velocity gained with the power in the mechanical powers? To what is the product of the weight, multiplied by the velocity of the power, always equal? What rule is given? 170. Of what does the wheel and axle consist? What is a cylinder?

Fig. 31.

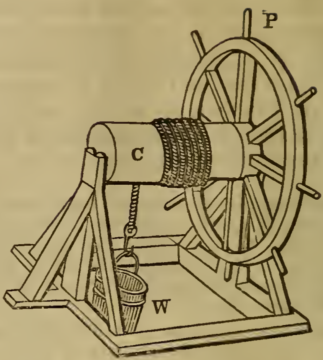
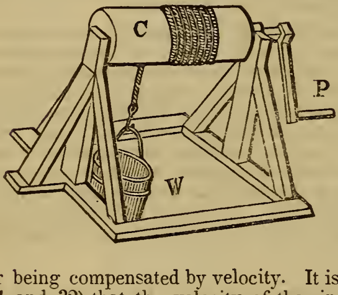


Illustration.——The wheel and axis, though made in many forms, will easily be understood by inspecting figures 31 and 32. In fig. 31 P represents the larger wheel where the power is applied; C the smaller wheel or cylinder, which is generally called the axis, and W the weight to be raised. The advantage gained is in proportion as the circumference of the wheel is greater than that of the axis. That is, if the circumference of the wheel is six times the circumference of the axis, then a power of one pound applied at the wheel will balance a power of six pounds on the axis.

Fig. 32.



Sometimes the axis is constructed with a winch or handle instead of the wheel, as in fig. 32, or with projecting spokes, as in fig. 31.

The principle upon which the wheel and axle is constructed is the same with that of the other mechanical powers, the want of power being compensated by velocity. It is evident (from the figures 31 and 32) that the velocity of the circumference of the wheel is as much greater than that of the axle as it is further from the centre of motion; for the wheel describes a great circle in the same time that the axle describes a small one; therefore the power is increased in the same proportion as the circumference of the wheel is greater than the axle. If the velocity of the wheel is twelve times greater than that of the axle, a power of one pound on the wheel will support a weight of twelve pounds on the axle.

171. In connexion with the wheel and axle, it is proper to mention the subject of complex wheel-work. It has already been stated that the velocity of the wheel

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What figures illustrate the wheel and axle? Explain. To what is the advantage gained in proportion? What does Fig 32 represent? Fig. 31? Upon what principle is the wheel and axle constructed? Explain by figures 31 and 32.

is greater than that of the axis; and this velocity is in proportion to the relative size of the wheel compared with that of the axis. Advantage is taken of this circumstance in driving machinery where the speed is to be increased or diminished. For it is evident that when quick motion is to be produced, that if the power is applied to the axis, and machinery is attached to the wheel, that rapid motion will be produced; and that, on the contrary, if the power be applied to the wheel and the machinery to the axis, that slow motion will be produced.

Fig. 33.

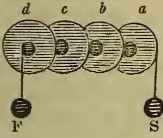

Illustration. Fig. 33 represents four wheels with their axles, each wheel acting on the axle of the adjoining wheel. F is the power applied to the axle of the wheel *d*. Now, supposing the circumference of each wheel to be six times the circumference of each axle, it is evident that each time the wheel *d* revolves it must cause the wheel *c* to make six revolutions, because the circumference of the wheel *d* is six times the circumference of the axle of *c*. In like manner the circumferences of the wheels *c* and *b*, acting respectively on the circumferences of the axles of the adjoining wheel, will communicate a velocity six times greater than their own, and while the wheel *d* makes one revolution the wheel *c* will make six, *b* thirty-six, and *a* two hundred and sixteen revolutions.

Reversing the figure, and applying the power at S which communicates with the circumference of the wheel *a*, it follows that *a* must perform six revolutions while *b* is performing one, thirty-six while *c*, and two hundred and sixteen while *d* performs one revolution. It will thus be perceived that a rapid or a slow motion may be communicated by various combinations of the wheels and axle.

172. The usual way of transmitting the action of the axles to the adjoining wheels is by means of teeth or cogs, raised on their surfaces. The cogs on the surface of the wheels are generally called teeth, and those on the surface of the axle are called leaves. The axle itself, when furnished with leaves, is called a *pinion*.

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171. How does the velocity of the wheel compare with that of the axle? To what is this velocity in proportion? Is any advantage taken of this, in driving machinery where the speed is to be increased or diminished? How would rapid motion be produced? Slow motion? Explain figure 33. 172. What is the usual way of transmitting the action of the axles to the adjoining wheels? What are the cogs on the surface of the wheel called? Those on the axle? What is a pinion?

Fig. 34.

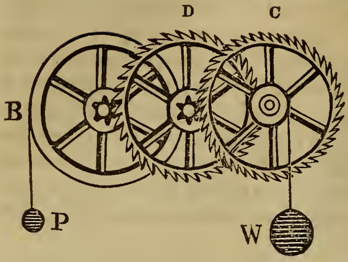


Illustration. Fig. 34 represents a connexion of cogged wheels. The wheel B being moved by a string around its circumference is a simple wheel without teeth. Its axis being furnished with cogs or *leaves* to which the teeth of the wheel D are fitted, communicates its motion to D, which, in like manner, moves the wheel C. The power P and the weight W must be attached to the circumference of the wheel or of the axis, according as a slow or a rapid motion is desired.

173. Wheels are sometimes turned by bands, as in figure 35; and the motion communicated may be direct or reversed by attaching the band, as represented in figs. 35 and 36. When the wheel and the axle from which it receives motion are intended to revolve in the same direction, the strap is not crossed, but is applied as in fig. 35. But when the wheel is to revolve in a direction contrary to the revolution of the axle, the strap is crossed, as in fig. 36.

Fig. 35.

Fig. 36.

174. Different directions may be given to the motion

Fig. 37.

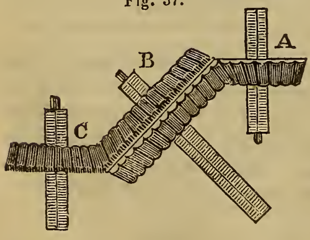
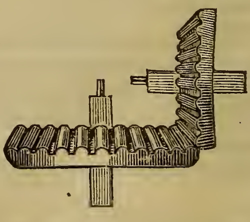


Fig. 38.



produced by wheels, by varying the position of their axles, and causing them to revolve in different planes, as

Explain Fig. 34. 173. By what are wheels sometimes turned? What figure represents one? In what way can the motion be made direct or reversed? What does Fig. 35 represent? Fig. 36? 174. In what way can different directions be given to the motion produced by wheels? What does Fig. 37 represent? Fig. 38?

in fig. 37; or by altering the shape and position of the teeth or cogs, as in fig. 38.

175. It remains to be observed that the wheel and axle are constructed on the same principle with the lever. The axle acts the part of the shorter arm of the lever, the wheel that of the longer arm.

176. The capstan, on board of ships and other vessels, is constructed on the principle of the wheel and axle. It consists of an axle placed uprightly, with a head or drum, pierced with holes for the lever, or levers, which supply the place of the wheel.

Windmills, Lathes, the common windlass, used for drawing water from wells, and the large wheels in mills are all constructed on the principle of the wheel and axle.

177. Wheels are a very essential part to most machines; they are applied in different ways, but when affixed to the axle their mechanical power is always in the same proportion; that is, as the circumference of the wheel exceeds that of the axle, so much will the power be increased. Therefore the larger the wheel and the smaller the axis, the greater will be the power obtained.

178. Fly wheels are heavy wheels used to accumulate power and distribute it equally among all the parts of a machine. They are caused to revolve by a force applied to the axle; and when once set in motion continue by their inertia to move for a long time. As their motion is steady and without sudden jerks, they serve to steady the power, and cause a machine to work with regularity.

179. Cranks are sometimes connected with the axle of a wheel, either to give or to receive its motion. They are made by bending the axle in such a manner as to form four right angles facing in different directions, as

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175. Upon what principle are the wheel and axle constructed? Explain how. 176. Upon what principle is the capstan on board of vessels constructed? Of what does it consist? What other things are mentioned as constructed upon this principle? 177. Are wheels an essential part to most machines? Are they applied in more than one way? When they are affixed to the axle, in what proportion is the power increased? 178. What are Fly wheels, and for what are they used? How are they made to revolve? When once set in motion, what causes them to move on for some time? Of what service are they in a machine? 179. For what are cranks, sometimes, connected with the axle of a wheel? How are they made?

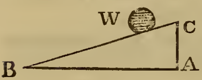
Fig. 39.

is represented in fig. 39. This is seen in lathes and many other kinds of machinery. Cranks are often used to change the motion from rectilinear to circular, or from circular to rectilinear.

180. The inclined plane consists of a plain surface inclined to the horizon.

Illustration. Fig. 40 represents an inclined plane. C A its height, C B its length, and W a weight which is to be moved on it. The advantage gained by the use of the inclined plain is in proportion as the length of the plane exceeds its perpendicular height. Thus, in this figure, if the length C B is four times the height C A, then a power of one pound will balance a weight of four pounds on the inclined plane.

Fig. 40.



181. The greater the inclination of the plane, the greater must be its perpendicular height, compared with its length, and, of course, the greater must be the power to elevate a weight along its surface.

Instances of the application of the inclined plane are very common. Sloping planks or pieces of timber leading into a cellar, and on which casks are rolled up and down; a plank or board with one end elevated on a step, for the convenience of trundling wheel-barrows, or rolling barrels into a store, &c., are inclined planes.

182. The advantage gained by the use of the inclined plane, like that of the other mechanical powers, is gained by a loss of time; for the weight, instead of moving directly up the ascent, must move the whole length of the plane. The power of gravity, also, instead of being confined to the perpendicular height, is spread over the whole length of the plane.

Chisels and other cutting instruments, which are *chamfered* or sloped only on one side, are constructed on the principle of the inclined plane.

183. The wedge consists of two inclined planes united at their bases.

What does figure 39 represent? For what are cranks often used? 180. What is an inclined plane? What figure represents an inclined plane? Explain the figure. To what is the advantage gained by the use of the inclined plane in proportion? 181. What follows from the greater or less inclination of the plane? Give some instances of the application of the inclined plane. 182. Is any time gained by the use of the inclined plane? Upon what principle are chisels and other cutting instruments, which are sloped only on one side, constructed? 183 Of what does the wedge consist?

Fig. 41.

Illustration. Fig. 41 represents a wedge. The line *a b* represents the base of each of the inclined planes of which it is composed, and at which they are united.

The advantage gained by the wedge is in proportion as its length exceeds one half its width.

The wedge is a very important mechanical power, used to split rocks, timber, &c., which could not be effected by any other power.

Axes, hatchets, knives, and all other cutting instruments chamfered or sloped on both sides, are constructed on the principle of the wedge.

184. The screw consists of an inclined plane, wound round a cylinder. It is generally composed of two parts, the screw and the nut; or, as they are generally called, the male and the female screw.

Illustration. Fig. 42.

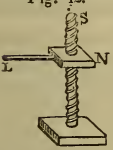


Fig. 42 represents the screw and the nut. S is the male screw, (which is an inclined plane wound round a cylinder,) N is the nut or female screw, which has a spiral groove, to which the thread of the male screw is accurately fitted. L is a lever attached to the nut, to which the power is applied. By turning the lever in one direction the nut ascends, and by turning it in the opposite direction the nut descends on the screw.* In this figure the screw is fixed and the nut is moveable.

Fig. 43.

Figure 43 represents another screw, which is movable. The nut is fixed to the frame, and the screw ascends or descends as the lever L is turned.

* Although the screw is mentioned as one of the six mechanical powers, it is, in reality, a compound power, consisting of a lever and an inclined plane. The power of the screw is estimated by the distance of the threads. The closer the threads the greater is the power; but here again the increase of power is procured by an increase of velocity, or a loss of time. For if the threads are a quarter of an inch apart, the power must move through the whole circumference of the circle described by the lever, in order to move the resistance a quarter of an inch. The screw, with its appendage the lever, is therefore used for the purpose of moving large or heavy bodies through small distances. Its power may be increased by lengthening the lever. The screw is applied to presses of all kinds where great power is required, such as book-binders' presses, cider and wine presses, &c.

What does Fig. 41 represent? To what is the advantage gained by the wedge in proportion? Of what use is the wedge? Give some examples of the wedge. 184. Of what does the screw consist? Of how many parts is it generally composed? What are they? What figure represents the screw and the nut? Explain the figure. How does figure 43 differ from the 42d? Is the screw a simple or compound power? How is the power of the screw estimated? How does the closeness of the thread affect the power? What is the use of the screw? How can its power be increased? To what is the screw applied?

185. All machines, instruments, implements, &c. are composed of one or more of the mechanical powers.*

186. By friction in machinery, is meant the resistance which bodies meet with in rubbing against each other.

187. There are two kinds of friction, the rolling and the sliding. The rolling friction is caused by the rolling of a circular body. The sliding friction is produced by the sliding or dragging of a flat surface. The sliding friction is overcome with more difficulty than the rolling. In calculating the power of a machine, an allowance must always be made for friction. It is usually computed that friction destroys one third of the power of a machine.†

188. Friction is caused by the unevenness of the surfaces which come into contact; ‡ and it is diminished in

* From what has been stated with regard to the mechanical powers, it appears that by their aid a man is enabled to perform works to which his unassisted, natural strength is wholly inadequate. But the power of all machines is limited by the strength of the materials of which they are composed. Iron, which is the strongest of all substances, will not resist a strain beyond a certain limit. Its cohesive attraction may be destroyed, and it can withstand no resistance which is stronger than its cohesive attraction. Besides the strength of the materials, it is necessary, also, to consider the *time* which is expended in the application of mechanical assistance. Archimedes is said to have boasted to Hiero, king of Syracuse, that if he would give him a place to stand upon he would move the whole world. In order to do this, Archimedes must himself have moved over as much more space than he moved the world, as the weight of the world exceeded his own weight; and it has been computed that he must have moved with the velocity of a cannon ball for a million of years, in order to move the earth the twenty-seven millionth part of an inch.

† The smallest impediment from friction is when finely polished iron is made to rub on bell metal; but even these are said to lose about one-eighth of their moving power. As the friction between rolling bodies is much less than in those that drag, the axle of large wheels is sometimes made to move on small wheels or rollers. These are called friction wheels, or friction rollers. They turn round their own centre as the wheel continues its motion.

‡ All bodies, how well soever they may be polished, have inequalities in their surfaces, which may be perceived by a microscope. When, therefore, the surfaces of two bodies come into contact, the prominent parts of the one will often fall into the hollow parts of the other, and cause more or less resistance to motion.

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185. Of what are all machines, instruments, implements, &c. composed? What aid is afforded to man by the use of the mechanical powers? By what is the power of all machines limited? Can the cohesive attraction of iron be destroyed? Can it withstand any resistance stronger than its cohesive attraction? What, beside the strength of the material, is necessary to be considered? What is related of Archimedes? How could Archimedes have done this? 186. What is meant by friction in machinery? 187. How many kinds of friction are there? What are they? How is the rolling friction produced? The sliding? Which is overcome with the less difficulty, the rolling or sliding? What allowance must always be made in calculating the power of a machine? What proportion of the power is usually computed to be destroyed by friction? Where is there the least friction? Between which is friction the less, rolling bodies or those that slide? 188. What causes friction? In what proportion is it diminished? In what manner can it be lessened?

proportion as the surfaces are smooth and well polished. Oil, grease, black-lead, or powdered soap-stone is used to lessen friction, because they act as a polish by filling up the cavities of the rubbing surfaces, and thus making them slide more easily over each other.

189. Wheels are used on vehicles to diminish the friction of the road. The larger the circumference of the wheel, the more readily it will overcome any obstacles, such as stones or inequalities in the road.*

190. The motion of all bodies is influenced by the medium † in which they move. By a medium is meant the substance or fluid which surrounds the body. Thus, air is the medium which surrounds a bird when flying; water is the medium which surrounds the fish when swimming, &c.

191. The resistance of a medium is in exact proportion to its density. A body falling through the air meets with less resistance than when falling through water, because water is a denser medium than air. If a machine could be worked *in vacuo*, (that is, in a vacuum or a space where there is neither air nor any thing else to impede it) and without friction, it would be perfect.

192. The main-spring of a watch (*See No.* 156) consists of a long ribbon of steel, closely coiled, and contained in a round box. It is employed instead of a weight to keep up the motion.

As the spring when closely coiled exerts a stronger force than when it is partly loosened, in order to correct this inequality, the chain through which it acts, is wound upon an axis surrounded by

* In descending a steep hill, the wheels of a carriage are often *locked*, (as it is called) that is, fastened in such a manner as to prevent their turning; and thus the rolling is converted into the sliding friction, and the vehicle descends more safely. Castors are put on the legs of tables and other articles of furniture, to facilitate the moving of them; and thus the sliding is converted into the rolling friction.

† The plural of this word is *media*.

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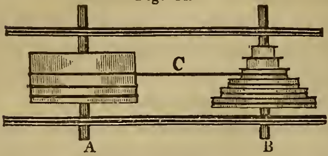
189. What is the use of wheels? In what proportion do they overcome the obstacles, such as stones, &c., in the road? Why, in descending a steep hill, are the wheels of a carriage often locked? How do castors, which are put upon furniture, facilitate the moving of it? 190. How is the motion of all bodies influenced? What is meant by a medium? What is the plural of medium? 191. To what is the resistance of a medium in proportion? What illustration is given? When would a machine be perfect? 192. Of what does the main-spring of a watch consist? What is its use? Does the spring exert a stronger force when closely coiled, or when partly loosened?

a spiral groove, (called a *fusee*) gradually increasing in diameter from the top to the bottom; so that in proportion as the strength of the spring is diminished it may act on a larger lever, or a larger wheel and axis.

Illustration. Fig. 44 represents a spring coiled in a round box, A. B is the fusee surrounded by a spiral groove on which the chain C is wound. When the watch is recently wound, the spring is in the greatest state of tension, and will, therefore, turn the fusee by the smallest groove, on the principle of the wheel and axle. As the spring loses its force by being partly unwound, it acts upon the larger circles of the fusee; nd the want of strength in the spring is compensated by the mechanical aid of a larger wheel and axle in the larger grooves. By this means the spring is made at all times to exert an equal power upon the fusee. The motion is communicated from the fusee by a cogged wheel which turns with the fusee.

Fig. 44.



193. The name of *governor* has been given to an ingenious piece of mechanism which is used to regulate the supply of steam in steam-engines, and of water in water-mills.

Fig. 45.

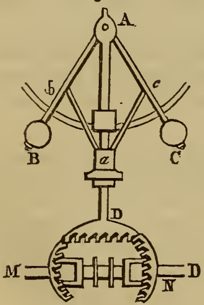


Illustration. Fig. 45 represents a governnor. A B and A C are two levers or arms, loaded with heavy balls at their extremities, B and C, and suspended by a joint at A, upon the extremity of a revolving shaft, A D. At *a* is a collar, or sliding box, connected with the levers by the rods *b a* and *c a*, with joints at their extremities. When the shaft A D revolves rapidly, the weights B and C will diverge or fly off, and cause the rods *b a* and *c a* to raise the collar or sliding-box. On the contrary, when the shaft, A D, revolves slowly, the weights B and C will fall by their own weight, and the rods *b a* and *c a* will cause the collar *a* to descend. The steam-valve in a steam-engine, or the sluice-gate of a water-wheel, being connected with the collar *a*, the supply of steam or water, which puts the works in motion, is thus regulated.*

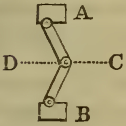
* In manufactures, there is one certain and determinate velocity with which the machinery should be moved, and which, if increased or diminished, would render

What is done in order to correct this inequality? What does Fig. 44 represent? Explain. 193. What is a governor? Explain Fig. 45. What is said in the note of the use of the governor?

194. The knee-joint, or as it is sometimes called the *toggle*-joint, consists of two rods or bars connected by a joint, and increasing rapidly in power as the two rods approach to the direction of a straight line.

Illustration. Fig. 46 represents a toggle-joint. A C and B C are the two rods connected by a joint C. A moving force applied in the direction C D acts with great and constantly increasing power to separate the parts A and B.

Fig. 46.



The operation of the toggle joint is seen in the iron joints which are used to uphold the tops of chaises. It is also used in various kinds of printing-presses, to obtain the greatest power at the moment of impression.

SECTION IX.

Hydrostatics.

195. Hydrostatics treats of the nature, gravity and pressure of fluids. (*See No.* 5.)

196. A fluid is a substance which yields to the slightest pressure, and the particles of which, having but a slight degree of cohesion, move easily among themselves. (*See No.* 19.)

197. A liquid differs from a fluid in its want of compressibility * and elasticity. (*See Numbers* 67 *and* 70.)

the machine unfit to perform the work it is designed to execute. Now, it frequently happens that the resistance is increased or diminished by some of the machines which are worked, being stopped, or others put on. The moving power, having this alteration in the resistance, would impart a greater or less velocity to the machinery, were it not for the regulating power of the governor, which increases or diminishes the supply of water or of steam, which is the moving power.

* The experiments (mentioned in number 26) made at Florence, many years ago, seemed to prove that some kinds of liquids, water, for instance, is wholly incompressible. Later experiments, particularly those of Mr. Jacob Perkins, of Newburyport, now in London, have proved that water is capable of a considerable degree of compression. Fluids, in general, have a voluntary tendency to expand (*See No.* 68.) when at liberty; but liquids will not expand without a change of

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194. Of what does the knee-joint or toggle-joint consist? In what proportion does it increase in power? What does figure 46 represent? Explain the figure. Give an instance of the operation of the toggle-joint? What is its use in printing-presses? 195. Of what does Hydrostatics treat? 196. What is a fluid? Does the attraction of cohesion have much influence on the particles of fluids? What follows from this? 197. How do fluids and liquids differ from each other? Can water be compressed? What is supposed to be the primary cause of the fluid form of bodies? What effect has heat upon bodies? What illustration is given?

198. Fluids gravitate in a more perfect manner than solids, because the strong cohesion of the particles of solid bodies in some measure counteracts the effects of gravity. Thus every particle of a fluid, which is not supported *on all sides*, will fall; but the cohesive attraction of the particles of solids enables the legs of a table to support a considerable weight. From this circumstance it appears that fluids have only a slight degree of cohesive attraction.

199. From the slight degree of cohesion in the particles of fluids it is inferred that they must be small, smooth and globular; smooth, because there appears to be no friction among them; and globular because touching each other but by a point would account for the slightness of their cohesion.

200. Fluids cannot be formed into figures, or preserved in heaps on account of their want of cohesion.

201. By the level or equilibrium of fluids is meant that every part of the surface is equally distant from the centre of the earth; that is, from the point to which gravity tends.

Illustration. All fluids have a tendency to preserve this equilibrium. Hence the surface of all fluids when in a state of rest must partake of the spherical form of the earth, and will therefore be bulging, not flat. This is very evident in large bodies of water, such as the ocean; and causes the masts of vessels at a distance to be seen before the hull. But the surfaces of small bodies of water bulge so little that they appear flat. This level or equilibrium of fluids is the natural result of the independent gravitation of each particle. The particles of a solid body being united by cohesive attraction, if any one of them is supported, it will uphold those also with which it is united. But when any particle of a fluid is unsupported, it is attracted down to the level of the surface of the fluid; and the readiness with which fluids yield to the slightest pressure

temperature. Heat is supposed to be the primary cause of the fluid form of bodies. (See No. 61.) It insinuates itself between the particles of bodies, and forces them asunder. Thus, for instance, ice, without heat, is a solid; with heat it becomes water, and with a greater degree of heat it expands into an elastic fluid called *steam*.

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198. Why do fluids gravitate in a more perfect manner than solids? How would you prove that fluids have only a slight degree of cohesive attraction? 199. What is inferred from the slight degree of cohesion in the particles of fluids? Why smooth? Why globular? 200. Why cannot fluids be formed into figures, or preserved in heaps? 201. What is meant by the level or equilibrium of fluids? Have all fluids a tendency to preserve this equilibrium? What follows from this? Why do some surfaces appear flat? Of what is this level or equilibrium of fluids the natural result? How does the gravitation of solid bodies differ from that of fluids?

will enable the particle, by its own weight, to penetrate the surface of the fluid and mix with it.

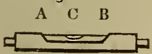
202. Fluids of different densities all preserve their own equilibrium.

Illustration. If a quantity of mercury, water, oil and air, be put into the same vessel, they will arrange themselves in the order of their specific gravities. (*See No.* 84.) The mercury will sink to the bottom, the water will stand above the mercury, the oil above the water, and the air above the oil; and the upper and under surfaces of each fluid will partake of the spherical form of the earth, to which they all respectively gravitate.

203. A water-level is an instrument constructed on the principle of the equilibrium of fluids. It consists of a glass tube, partly filled with water, and closed at both ends. When the tube is not perfectly horizontal —that is, if one end of the tube be lower than the other—the water will run to the lower end. By this means the level of any situation to which the instrument is applied may be ascertained.

Illustration. Fig. 47 represents a water-level. A B is a glass tube partly filled with water. C is a bubble of air occupying the space not filled by the water. When both ends of the tube are on a level, the air bubble will remain in the centre of the tube; but if either end of the tube be depressed, the water will descend and the air bubble will rise. The glass tube when used is generally set in a wooden or brass box. It is an instrument much used by carpenters, masons, surveyors, &c.

Fig. 47.



204. The inertia (*See No.* 39.) of fluids is considerably less than that of solid bodies; because the strong cohesion of the particles of solid bodies causes them *unitedly* to resist every change of state, whether of motion or rest; but the resistance of the particles of fluids may be more easily overcome, on account of their want of cohesion, which prevents them from acting *together*. Solid bodies, therefore, gravitate in masses— their parts being so connected as to form a whole, their weight is concentrated in a single point called the cen-

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202. Do fluids of different densities all preserve their own equilibrium? What illustration is given to prove this? 203. Upon what principle is a water-level constructed? Of what does it consist? For what is it used? What figure represents a water-level? Explain the figure. 204. How does the inertia of fluids compare with that of solid bodies? Why? In what manner do solid bodies gravitate? What is the centre of gravity?

tre of gravity; while every particle of a fluid may be considered as a separate mass, gravitating independently of each other. It is for this reason that a body of water, in falling, does less injury than a solid body of the same weight. But if the water be converted into ice, the particles losing their fluid form, and being united by cohesive attraction, gravitate unitedly in one mass.

205. The effect of gravity on the particles of fluids is peculiar. It causes them not only to press downwards like solids, but also upwards, sideways, and in every direction. So long as the equality of pressure is undisturbed, every particle will remain at rest. If the fluid be disturbed by agitating it, the equality of pressure will be disturbed, and the fluid will not rest until the equilibrium is restored.

Illustration. The downward pressure of fluids is shown by making an aperture in the bottom of a vessel of water. Every particle of the fluid above the aperture will run downwards through the opening.

The lateral pressure is shown by making the aperture at the side of the vessel. The fluid will then escape through the aperture at the side.

The upward pressure is shown by taking a glass tube, open at both ends, putting a cork into one end, (or stopping it up with the finger) and immersing the other in the water. The water will not rise in the tube. But the moment that the cork is taken out, (or the finger is removed,) the fluid will rise in the tube to a level with the surrounding water.

206. The particles of fluids are not arranged in regular columns, one above another, for if they were, there would be no lateral pressure.

Illustration. Fig. 48 represents the magnified particles of a fluid arranged in regular columns. It is evident, from an inspection of the figure, that the effect of gravity upon each particle will be to carry it *downward* only by a force equal to its own weight, added to the weight of each particle above it. Fig. 49. represents the manner in which the particles are probably arranged, and it appears by that figure that each particle presses between two particles beneath it, and that these last must suffer a lateral pressure.

Fig. 8.

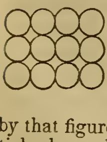
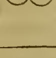


Fig. 49.



205. What effect has gravity on the particles of fluids? How long will the particles of fluids remain at rest? How is the downward pressure of fluids shown? The lateral pressure? The upward pressure? 206. Are the particles of fluids arranged in regular columns, one above another? What would be the consequence if they were? Explain Fig. 48. What does figure 49 represent?

207. The pressure of a fluid is in proportion to the perpendicular distance from the surface; that is, the deeper the fluid the greater will be the pressure. This pressure is exerted in every direction, so that all the parts at the same depth press each other with equal force.

Illustrations. A bladder, filled with air, being immersed in water, will be contracted in size, on account of the pressure of the water in all directions; and the deeper it is immersed the more will it be contracted.

An empty bottle, being corked, and by means of a weight let down to a certain depth in the sea, will either be broken by the pressure, or the cork will be driven into it, and the bottle be filled with water. This will take place even if the cork be fastened with wire and sealed. But a bottle filled with water, or any other liquid, may be let down to any depth without damage, because, in this case, the internal pressure is equal to the external.*

208. From what has now been stated, it appears that the lateral pressure proceeds entirely from the pressure downwards, or, in other words, from the weight of the liquid above; and that consequently the lower an orifice is made in a vessel containing water or any other liquid, the greater will be the force and velocity with which the liquid will rush out.

* '*Experiments at Sea.*—We are indebted to a friend, who has just arrived from Europe, says the Baltimore Gazette, for the following experiments made on board the Charlemagne:

'26th of September, 1836, the weather being calm, I corked an empty wine bottle and tied a piece of linen over the cork; I then sank it into the sea six hundred feet; when drawn immediately up again, the cork was inside, the linen remained as it was placed, and the bottle was filled with water.

'I next made a noose of strong twine around the bottom of the cork, which I forced into the empty bottle, lashed the twine securely to the neck of the bottle, and sank the bottle six hundred feet. Upon drawing it up immediately the cork was found inside, having forced its way by the twine, and in so doing had broken itself in two pieces; the bottle was filled with water.

'I then made a stopper of white pine, long enough to reach to the bottom of the bottle; after forcing this stopper into the bottle, I cut it off about half an inch above the top of the bottle and drove two wedges, of the same wood, into the stopper. I sank it 600 feet, and upon drawing it up immediately the stopper remained as I placed it, and there was about a gill of water in the bottle, which remained unbroken. The water must have forced its way through the pores of the

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207. To what is the pressure of a fluid in proportion? In what direction is this pressure exerted? What illustrations are given to prove this? Why can a bottle, filled with water, or any other liquid, be let down to any depth without injury? What experiment is mentioned in the note? 208. What causes the lateral pressure? What follows from this?

Fig. 50.

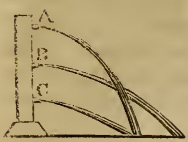


Illustration. Fig. 50 represents a vessel of water, with orifices at the side at different distances from the surface. The different curves in that figure, describing the course of the liquid in running out of the vessel, show the force of the pressure on the liquid at different depths. At A the pressure is the least, because there is less weight of fluid above it. At B and C the fluid is driven downwards by the weight of that portion above, and it will be strongest at C.

209. As the lateral pressure arises solely from the downward pressure, it is not affected by the width or the length of the vessel in which it is contained, but merely by its depth; for as every particle acts independently of the rest, it is only the column of particles immediately above the orifice that can weigh upon and press out the water.

210. The lateral pressure on one side of a cubical vessel will be equal only to half of the pressure downwards; for every particle at the bottom of the vessel is pressed upon by a column of the whole depth of the fluid, whilst the lateral pressure diminishes from the bottom upwards to the surface, where the particles have no pressure.

211. The upward pressure of fluids, although *apparently* in opposition to the principles of gravity, is but a necessary consequence of the operation of that principle; or, in other words, *the pressure upwards, as well as the pressure downwards* is caused by gravity.

Illustration. When water is poured into a vessel with a spout (like a tea-pot, for instance,) the water rises in the spout to a level with that in the body of the vessel. The particles of water at the bottom of the vessel, are pressed upon by the particles above them, and to this pressure they will yield, if there is any mode of making

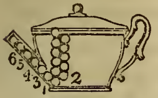
wooden stopper, although wedged as aforesaid; and had the bottle remained sunk long enough, there is no doubt that it would have been filled with water.'

It is the opinion of some philosophers that the pressure at very great depths of the sea is so great that the water is condensed into a solid state; and that at or near the centre of the earth this pressure converts the whole into a solid mass of fire.

Explain Fig. 50. 209. Does the length or the width of the vessel in which it is contained have any effect upon the lateral pressure? By what is it affected? 210. How does the lateral pressure on one side of a cubical vessel compare with the pressure downward? How would you explain this? 211. What causes the upward and downward pressures?

way for the particles above them. As they cannot descend through the bottom of the vessel they will change their direction and rise in the spout. Fig. 51 represents a tea-pot, and the columns of balls represent the particles of water magnified. From an inspection of the figure it appears that the particle numbered 1, at the bottom, will be pressed laterally by the particle numbered 2, and by this pressure forced into the spout, where meeting with the particle 3 it presses it upwards, and this pressure will be continued from 3 to 4, from 4 to 5, and so on till the water in the spout has risen to a level with that in the body of the vessel. If water be poured into the spout the water will rise in the same manner in the body of the vessel; from which it appears that the force of pressure depends entirely on the height, and not on the length or breadth of the column of fluid, as is stated in No. 209.

Fig. 51.



The Hydrostatic Bellows. From what has now been stated it appears that any quantity of fluid, however small, may be made to counterpoise or balance any quantity, however large. This is called the hydrostatical paradox, and it is shown by an instrument called the hydrostatical bellows.

Fig. 52.

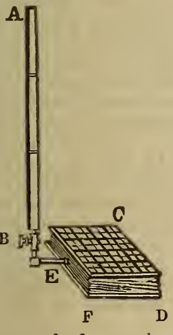


Fig. 52 represents the hydrostatic bellows. A B is a long tube, one inch square. C D E F are the bellows, consisting of two boards, eight inches square, connected by broad pieces of leather, or india rubber cloth, in the manner of a pair of common bellows. By putting one pound of water in the tube, it will raise sixty-four pounds on the bellows.* The Hydrostatic Bellows belonging to "the Boston School set" are eight inches square, marked into sixty four square inches, on the top—or into sixteen squares of two inches each. There are two square tubes connected with the bellows, one of one inch and another of two inches in diameter, or a sixty-four and a sixteenth of the surface of the bellows. If a pound of water be put into the larger tube, sixteen pounds may be raised on the bellows, but if it be put into the smaller tube it will raise sixty-four pounds.

* The fundamental principle of mechanics or the laws of motion is here also in full force, namely, that what is gained in power is lost either in time or in space; for although one pound is here made to raise sixty-four pounds, it is to be remarked that the distance or height to which the sixty-four pounds will rise is as much less than that over which the one pound will move, as sixty-four is greater than one.

Illustrate this by figure 51. Upon what does the force of pressure depend? What is meant by the hydrostatic paradox? What is the use of the hydrostatic bellows? What Fig. represents the hydrostatic bellows? Explain the Fig. What is the fundamental principle of mechanics? Is this the principle of the hydrostatic bellows?

When the bellows have been filled with water, turn the stop cock; take out the tube and substitute the straight jet, (*See Fig.* 72.) and the water will be forced out to a height nearly as great as that of the water in the tube. Were it not for the resistance of the air it would rise to the same height.

212. If water be confined in any vessel, and a pressure to any amount be exerted on a square inch of that water, a pressure to an equal amount will be transmitted to every square inch of the surface of the vessel in which the water is confined.*

Fig. 53.

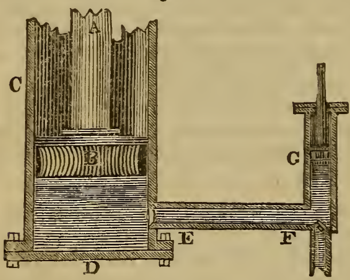


Illustration. It is upon this principle that Bramah's hydrostatic press, represented in Fig. 53, is constructed. A large solid plug or piston, A B, is constructed so as to move water-tight in a cylinder C D. The space beneath the piston is filled with water, and communicates by a pipe E F with a small forcing-pump worked by the piston G, by which the water is forced into the chamber of the cylinder C D below the great piston. Let us now suppose the entire space between the two pistons to be filled with water, and a pressure of one pound exerted on the water by means of the piston G of the forcing-pump. Let us also suppose that the diameter of the piston G is a quarter of an inch, and that the diameter of the piston B is one foot. In that case, the base of the piston B, which is pressed by the water, is 2304 times the base of the piston G, which presses the water, and in virtue of the power of transmitting pressure, a pressure of one pound will be transmitted to every part of the base of the greater piston, which is equal to the base of the less. Thus an urging pressure of one pound on the base of the piston G, will produce a pressure of 2304*lbs.* against the base of the greater piston B.

*This property of fluids, therefore, seems to invest us with a power of increasing the intensity of a pressure exerted by a comparatively small force, without any other limit than that of the strength of the materials of which the engine itself is constructed. It also enables us with great facility to transmit the motion and force of one machine to another, in cases where local circumstances preclude the possibility of instituting any ordinary mechanical connexion between the two machines. Thus, merely by means of water-pipes, the force of a machine may be transmitted to any distance, and over inequalities of ground, or through any other obstructions.

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212. What fact is mentioned in this number with regard to the pressure on water? Upon what principle is Bramah's hydrostatic press constructed? What Fig. represents this? Explain the Fig. What advantages result from that property of fluids stated in No. 212?

213. A fluid specifically lighter than another fluid will float upon its surface.*

214. A body specifically lighter than a fluid will sink in the fluid until it has displaced a portion of the fluid equal in weight to itself.

Illustration. If a piece of cork is placed in a vessel of water, about one third part of the cork will sink below, and the remainder will stand above the surface of the water; thereby displacing a portion of water equal in bulk to about a third part of the cork, and this quantity of water is equal in weight to the whole of the cork; because the specific gravity (*See No.* 84.) of water is about three times as great as that of cork. †

215. The standard which has been adopted to estimate the specific gravity (*See No.* 84.) of substances in general, is rain or distilled water.

Explanation. As heat expands and cold condenses all metals, their specific gravity cannot be the same in summer that it is in winter. For this reason they will not serve as a standard to estimate the specific gravity of other bodies. The reason that *distilled* water is used is, that spring, well, or river water is seldom perfectly pure; and the various substances mixed with it affect its weight. But distilled water is uniformly of the same weight. Taking, therefore, a certain quantity of rain or distilled water, we find that a *quantity* of gold, *equal in bulk* to the water, will weigh nearly twenty times as much as the water; of lead, nearly twelve times as much; while oil, spirit, cork, &c. will weigh less than the water.‡

* The slaves in the West Indies, it is said, steal rum by inserting the long neck of a bottle, full of water, through the top aperture of the rum cask. The water falls out of the bottle into the cask, while the lighter rum ascends in its stead.

† It is on the same principle that boats, ships, &c. although composed of materials heavier than water, are made to float. From their peculiar shapo they are made to set lightly on the water. The extent of the surface presented to the water counterbalances the weight of the materials, and the vessel sinks to such a depth as will cause it to displace a portion of water equal in weight to the whole weight of the vessel. From a knowledge of the specific gravity of water, and the materials of which a vessel is composed, rules have been formed by which to estimate the tonnage of vessels—that is to say, the weight which the vessel will sustain without sinking.

‡ The following table shows the specific gravity of the substances therein mentioned. It is to be understood that all substances whose specific gravity is greater than water, will sink when immersed in it, and that all whose specific gravity is less than that of water, will float in it. Let us then take a quantity of water

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213. When will one fluid float upon another? 214. What is stated with regard to a body specifically lighter than a fluid? What illustration of this is given? How do the specific gravities of water and cork compare with each other? Upon what principle is it that boats, ships, &c. are made to float upon the water? What rules have been formed from the knowledge of the specific gravity of water and the materials of which vessels are composed? 215. What standard has been adopted to estimate the specific gravity of substances in general? Why could not metals have been adopted? Why is distilled water used?

216. The specific gravity of bodies that will sink in water is ascertained by weighing them first in water, and then out of the water, and dividing the weight out of the water by the loss of weight in water.

Fig. 54.

Fig. 54 represents the scales for ascertaining the specific gravity of bodies. One scale is shorter than the other, and a hook is attached to the bottom of the scale to which substances, whose specific gravity is sought may be attached and sunk in water.

Illustration. Suppose a cubic inch of gold weighs 19 ounces when weighed out of the water, and but 18 ounces* when weighed in water—the loss in water is one ounce. The weight out of water, 19 ounces, being divided by one (the loss in water) gives 19. The specific gravity of gold, then, would be 19, or, in other words, gold is nineteen times heavier than water.

which will weigh exactly one pound; a quantity of the substances specified in the table, of the same bulk, will weigh as follows:

Platinum,	23.	pounds.	Chalk,	1.793	pounds.	Living men,	.891	pounds.
Fine Gold,	19.640	'	Coal,	1.250	'	Ash,	.800	'
Mercury,	14.019	'	Mahogany,	1.063	'	Beach,	.700	'
Lead,	11.525	'	Milk,	1.034	'	Elm,	.600	'
Silver,	11.091	'	Box wood,	1.030	'	Fir,	.500	'
Copper,	9.000	'	Rain water,	1.000	'	Cork,	.240	'
Iron	7.645	'	Oil,	.920	'	Common Air,	.0011	'
Marble,	2.705	'	Ice,	.908	'	Hydrogen gas,	.000105	'
Glass,	3.000	'	Brandy,	.820	'			

A cubic foot of water weighs one thousand avoirdupois ounces. By multiplying the number opposite to any article in the above table by one thousand, we obtain the weight of a cubic foot of that article, in ounces. Thus a cubic foot of platinum is 23000 ounces in weight.

In the above table it appears that the specific gravity of *living men* is about one ninth less than that of common water. So long, therefore, as the lungs can be kept free from water, a person, although unacquainted with the art of swimming, will not completely sink, provided the hands and arms be kept under the water.

The specific gravity of sea water is greater than that of the water of lakes and rivers, on account of the salt contained in it. On this account the water of lakes and rivers has less buoyancy, and it is more difficult to swim in it.

* Gold will weigh less in the water than out of it, on account of the upward pressure of the particles of water, which in some measure supports the gold, and by so doing diminishes its weight. Now, as the upward pressure of these particles is exactly sufficient to balance the downward pressure of a quantity of water of exactly the same dimensions with the gold, it follows that the gold will lose exactly as much of its weight in water as a quantity of water of the same di-

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What bodies will sink when immersed in water? What will float? What is the weight of a cubic foot of water? What is the use of the above table? How does the specific gravity of living men compare with that of water? Which is the greater, the specific gravity of sea water, or of lakes and rivers? Why? 216. How is the specific gravity of bodies, that will sink in water, ascertained? What illustration is given? Explain Fig. 54. Why will gold weigh less in the water than out of it? How does this upward pressure of the particles compare with the downward pressure of a quantity of water of the same dimensions? What follows from this?

217. The specific gravity of a body that will not sink in water, is ascertainad by dividing its weight, by the sum of its weight, added to the loss of weight which it occasions in a heavy body previously balanced in water.*

Illustration. If a body lighter than water weighs six ounces, and on being attached to a heavy body, balanced in water, is found to occasion it to lose twelve ounces of its weight, its specific gravity is determined by dividing its weight (six ounces) by the sum of its weight, added to the loss of weight it occasions in the heavy body, namely, six added to twelve, which, in other words, is 6 divided by 18, or 6-18, which is 1-3d.

218. An hydrometer is an instrument to ascertain the specific gravity of liquids.

Illustration. The hydrometer is constructed on the principle, that the greater the weight of a liquid, the greater will be its buoyancy. The hydrometer is made in a variety of forms, but it in general consists of a hollow ball of silver, glass, or other material,

dimensions with the gold will weigh. And this rule applies to all bodies heavier than water, that are immersed in it. *They will lose as much of their weight in water as a quantity of water of their own dimensions weighs.* All bodies, therefore, of the same size, lose the same quantity of their weight in water. Hence, the specific gravity of a body is the weight of a body, compared with that of water. As a body loses a quantity of its weight when immersed in water, it follows that when the body is lifted from the water, that portion of its weight which it had lost will be restored. This is the reason that a bucket of water, drawn from a well, is heavier when it rises above the surface of the water in the well, than it is while it remains below the surface. For the same reason our limbs feel heavy in leaving a bath.

* The method of ascertaining the specific gravities of bodies was discovered accidentally by Archimedes. He had been employed by the king of Syracuse to investigate the metals of a golden crown which he suspected had been adulterated by the workmen. The philosopher labored at the problem in vain, till going one day into the bath, he perceived that the water rose in the bath in proportion to the bulk of his body. He instantly perceived that any other substance of equal size would raise the water just as much, though one of *equal* weight and *less* bulk could not produce the same effect. He then obtained two masses, one of gold and one of silver, each equal in weight to the crown, and having filled a vessel very accurately with water, he first plunged the silver mass into it, and observed the quantity of water that flowed over; he then did the same with the gold, and found that a less quantity had passed over than before. Hence he inferred that, though of equal weight, the bulk of the silver was greater than that of the gold, and that the quantity of water displaced was, in each experiment, equal to the bulk of the metal. He next made trial with the crown, and found it displaced more water than the gold, and less than the silver, which led him to conclude, that it was neither pure gold nor pure silver.

What rule is given with regard to all bodies heavier than water that are immersed in it? What is the specific gravity of a body? What is the reason that a bucket of water, drawn from a well, is heavier when it rises above the surface of the water than while it is below it? 217. How can the specific gravity of bodies that will not sink in water be ascertained? What illustration is given? By whom was the method of ascertaining the specific gravities of bodies discovered? In what manner did he ascertain it? 218. What is an hydrometer? Upon what principle is it constructed? Explain its construction.

with a graduated scale rising from the upper part. A weight is attached below the ball. When the instrument, thus constructed, is immersed in a fluid, the specific gravity of the fluid is estimated by the portion of the scale that remains above the surface of the fluid. The greater the specific gravity of the fluid the less will the scale sink.

SECTION X.

Hydraulics.

219. Hydraulics treats of the motion of fluids, particularly of water; and the construction of all kinds of instruments and machines for moving them.*

220. Water, in its motion, is retarded by the friction of the bottom and sides of the vessel or channel through which it passes. For this reason the velocity of the

* In the second illustration, under No. 38, page 12, some account is given of the chemical action of heat upon water; and the reason is there given why the rain which falls upon the earth, and sinks into it, does not, in the course of time, injure its solidity. The cause of the ascent of steam, or vapor, may be found in its specific gravity. It may here be stated that rain, snow and hail are formed by the condensation of the particles of vapor in the upper regions of the atmosphere. The watery particles coming within the sphere of each other's attractions, unite in the form of a drop, which being heavier than the air, falls to the earth. Snow and hail differ from rain only in the different degrees of temperature at which the particles unite. When rain, snow, or hail fall, part of it reascends in the form of vapor, to form clouds, &c., part is absorbed by the roots of vegetables, and part descends into the earth to form springs. The springs form brooks, rivulets, rivers, &c. and descend to the ocean, where, being again heated by the sun, the water rises in the form of vapor, again forms clouds, and again descends in rain, snow, hail, &c. The specific gravity of the watery particles which constitute vapor, is less than that of the air near the surface of the earth; they will, therefore, ascend until they reach a portion of the atmosphere of the same specific gravity with themselves. But the constant accession of fresh vapor from the earth, and the loss of heat, causes several particles to come within the sphere of each other's attraction, as has been stated above, and they unite in the form of a drop, the specific gravity of which being greater than that of the atmosphere, it will fall in the form of rain. Water, as it descends in rain, snow, or hail, is perfectly pure, but when it has fallen to the earth, it mixes with the various substances through which it passes, which give it a species of flavor, without affecting its transparency.

In what proportion does the scale sink? 219. Of what does hydraulics treat? What is the cause of the ascent of steam or vapor? How are the particles of this vapor formed into rain, snow, or hail? How long will these particles remain in the upper regions? What becomes of them after they have fallen? 220. What retards the motion of water?

surface of a canal or river is always greater than that of any other part.*

221. A fluid running from an orifice in a vessel is discharged with double the rapidity when the vessel from which it flows is kept constantly full.

222. When a fluid spouts from several orifices in the side of a vessel, it is thrown to the greatest distance from the orifice nearest to the centre.†

223. A vessel filled with any liquid will discharge a greater quantity of the liquid through an orifice to which a short pipe is fitted, than through an orifice of the same size without a pipe.‡ If the pipe projects into the vessel the quantity discharged will be diminished instead of increased by the pipe.

224. The quantity of a fluid discharged through a pipe or an orifice is increased by heating the liquid; because heat diminishes the cohesion of the particles, which exists, to a certain degree, in all liquids.

225. The velocity of a current of water may be ascertained by immersing in it a bent tube, shaped like a tunnel at the end which is immersed.

* In consequence of the friction of the banks and beds of rivers, and the numerous obstacles they meet in their circuitous course, their progress is slow. If it were not for these impediments, the velocity which the waters would acquire would produce very disastrous consequences. An inclination of three inches in a mile, in the bed of a river, will give the current a velocity of about three miles an hour.

† If the vessel be elevated, the lowest orifice will discharge the fluid to the greatest distance, but when the vessel is placed low, the fluid will reach the plane before its projectile force is expended. [*See No.* 198.]

‡ This is caused by the cross currents made by the rushing of the water from different directions towards the sharp-edged orifice. The pipe smooths the passage of the liquid.

Why does the surface of a canal or river have a greater velocity than any other part? What benefit results from friction retarding the motion of water? 221. Does the fulness of a vessel from the orifice of which a fluid is running, have any effect upon its velocity? 222. When a fluid spouts from several orifices in the side of a vessel, from which is it thrown to the greatest distance? If the vessel be elevated, from which will it be discharged to the greatest distance? Why will not this be the case when the vessel is placed low? 223. What effect will a pipe, fitted to an orifice, have with regard to the quantity discharged? What will be the effect if the pipe project into the vessel? How is this caused? 224. How can the quantity discharged through a pipe or orifice, be increased? Why will heat increase it? 225. How can the velocity of a current of water be ascertained?

Fig. 55.

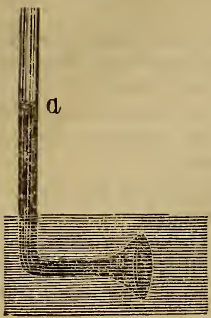

Illustration. Fig. 55 is a tube shaped like a tunnel, with the larger end immersed in an opposite direction to the current. The rapidity of the current is estimated by the height to which the water is forced into the tube, above the surface of the current. By such an instrument the comparative velocity of different streams, or the same stream at different times, may be estimated.

226. Waves are caused by the friction between air and water.*

227. The instruments used for raising or drawing water or other liquids, are the syphon, the common pump,† the chain pump, the forcing pump, and the screw of Archimēdes.

228. The screw of Archimēdes is a machine said to have been invented by the philosopher Archimēdes, for raising water and draining the lands of Egypt, about 200 years before the Christian era.

Fig. 56.

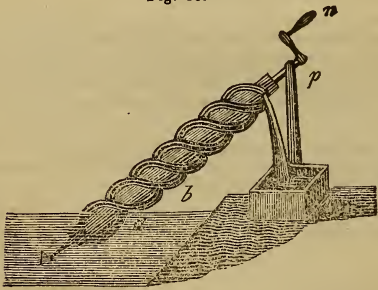

Illustration. Figure 56 represents the screw of Archimedes. A single tube, or two tubes, are wound in the form of a screw around a shaft or cylinder, supported by the prop and the pivot A, and turned by the handle, *n*. As the end of the tube dips into the water, it is filled with the fluid,

* It has been said, (and the experiment has been tried,) that when oil is poured on the windward side of a pond, the whole surface will become smooth. The oil protects the water from the friction of the wind or air. It is said, also, that boats have been preserved in a raging surf, in consequence of the sailors having emptied a barrel of oil on the water, which has thus been protected from the friction of the air.

† The common pump, and the forcing pump will be explained in connexion with pneumatics.

What does Fig. 55 represent? How is the rapidity of the current estimated? What is the use of the instrument? What causes waves? What is sometime done to remove this friction? 227. What instruments are used for raising liquids? 228. What is said of the screw of Archimedes? Explain the use of this screw by Fig. 56.

which is forced up the tube by every successive revolution, until it is discharged at the upper end.

229. The chain pump is a kind of pump used on board of ships.

Fig. 57.

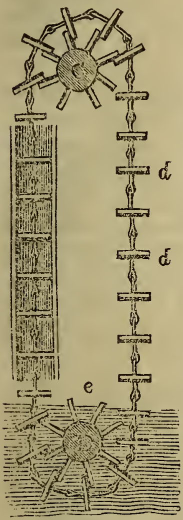

Illustration. Fig. 57 represents a chain pump. It consists of a square box through which a number of square boards or buckets, connected by a chain, are made to pass. The chain passes over the wheel C and under the wheel D, which is under water. The buckets are made to fit the box, but not so as to create much friction. The upper wheel, C, is turned by a crank, (not represented in the Fig.) which causes the chain with the buckets attached to pass through the box. Each bucket, as it enters the box, lifts up the water above it, and discharges it at the top.

230. Springs and rivulets are formed by the water, from rain, snow, &c. which penetrates the earth, and descends until it meets a substance which it cannot penetrate. A reservoir is then formed by the union of small streams under ground, and the water continues to accumulate until it finds an outlet.

Fig. 58.

Illustration. Fig. 58 represents a body of water, A, formed by the continual accession of water received from the ducts or rivulets, *a a a a*. When the water rises as high as B it finds a passage out of the cavity, and runs on till it makes its way out of the ground at the side of a hill, and then forms a spring at C.

231. A spring will rise nearly as high, but cannot rise higher than the reservoir from whence it issues.

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229. Where is the chain pump used? What Fig. represents it? Explain the Fig. 230. How are springs and rivulets formed? Explain Fig. 58.

Water may be conveyed over hills and valleys in bent pipes and tubes, or through natural passages, to any height which is not greater than the level of the reservoir from whence it flows.*

232. Fountains are formed by water carried through natural or artificial ducts from a reservoir. The water will spout through the ducts to nearly † the height of the surface of the reservoir.

233. The Syphon ‡ is a tube bent in the form of the letter U, one side being a little longer than the other.

Illustration. Fig. 58 represents the Syphon of the Boston School set. A syphon is used by filling it with water or some other fluid, then stopping both ends, and in this state immersing the shorter leg or side into a vessel containing a liquid. The ends then being unstopped, the liquid will run through the syphon until the vessel is emptied. In performing this experiment, the end of the syphon which is out of the water must always be below the surface of the water in the vessel. The syphon may be used to show the equilibrium of fluids, by pouring in a small quantity of mercury and thirteen and a half inches of water into the largest part. The liquids will rise in each side or leg of the syphon, in height, proportioned to their specific gravity. The mercury being of specific gravity thirteen times greater than that of water, will balance thirteen times its bulk of water. Consequently the water will rise thirteen times as high on one side of the syphon as the mercury is on the other. But if one liquid only is poured into the syphon it will rise to the same height in both sides or legs of the syphon. Any other liquids may be used with similar effect; namely, the lighter liquid will rise as much higher on one side of the syphon than the other as the specific gravity of one fluid exceeds that of the other.

Fig. 59.

* The ancient Romans, ignorant of this property of fluids, constructed vast aqueducts across valleys, at great expense, to convey water over them. The moderns effect the same object by means of wooden, metallic or stone pipes.

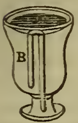
† The resistance of the air prevents the fluids from rising to quite the same height with the reservoir.

‡ The Syphon belonging to "*the Boston School set*" is a glass tube, the longer arm of which is about 6, and the shorter arm about 21 inches in length. Besides the experiments made with it, which are mentioned above, the following may be performed. 1. Screw the stop cock (*See Fig.* 66.) into the short end of the syphon ; close the stop cock, and pour a quantity of mercury into the longest arm. The air contained in the shorter arm will prevent the mercury from rising in that arm, but on turning the stop cock, the mercury will rise to an equilibrium in both arms.

231. How high will a spring rise? 232. How are fountains formed? How high will the water spout through the ducts? What prevents the fluids from rising to the same height with the reservoir? 233. What is the syphon? In what manner is the syphon used? How can the syphon be used to show the equilibrium of fluids? How high will the liquid rise in each side of the syphon? What experiment, made with the syphon, is mentioned in the note.

234. Tantalus' cup consists of a goblet containing a small figure of a man. A syphon is concealed within the figure, which empties the water from the goblet as fast as it is poured in, so that the glass can never be filled. Fig. 60 represents the cup with the syphon. The figure of the man is not represented, in order that the position of the syphon may be seen.

Fig. 60.



235. Water, by means of its weight or its force when in motion, becomes a mechanical agent of great power. It is used to propel or turn wheels of different construction, which being connected with machinery of various kinds, form mills, &c.

236. There are three kinds of water-wheels, called undershot, overshot, and breast wheels.

237. The Overshot wheel is a wheel set in motion by the weight of water flowing upon it. It receives its motion at the top.

Fig. 61.

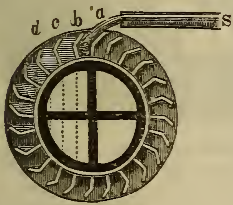


Illustration. Fig. 61 represents the overshot wheel. It consists of a wheel turning on an axis, (not represented in the Fig.) with compartments called buckets, *a b c d*, &c. at the circumference, which are successively filled with water from the stream S. The weight of the water in the buckets causes the wheel to turn, and the buckets being gradually inverted are emptied as they descend. It will be seen, from an inspection of the figure, that the buckets in the descending side of the wheel are always filled, or partly filled, while those in the opposite or ascending part are always empty until they are again presented to the stream. This kind of wheel is the most powerful of all the water-wheels.

238. The Undershot wheel is a wheel which is set in motion by the motion of the water. It receives its im pulse at the bottom.

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234. What is Tantalus' cup? What does Fig. 60 represent? 235. How, and for what purposes is water used as a mechanical agent? 236. How many kinds of water-wheels are there? What are they? 237 What is the overshot wheel? Where does it receive its motion? Explain Fig. 61 What causes the wheel to turn? How does this wheel compare in power with the other water-wheels? 238. What is the undershot wheel? Where does it receive its motion?

Fig. 62.

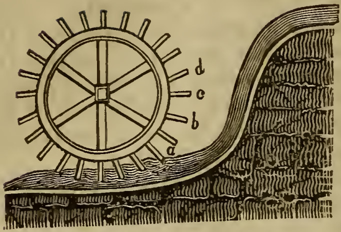


Illustration. Fig. 62 represents the undershot wheel. Instead of buckets at the circumference, it is furnished with plane surfaces, called float-boards, *a b c d*, &c. which receive the impulse of the water, and cause the wheel to revolve.

239. The Breast wheel is a wheel which receives the water at about half its own height, or at the level of its axis. It is set in motion both by the weight and the motion of the water.

Fig. 63.

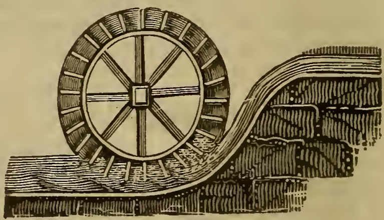


Illustration. Fig. 63 represents a breast wheel. It is furnished either with buckets, or with float-boards, fitting the water course.

In all the wheels which have been described, the motion given to the wheel, is communicated to other machinery or gearing, as it is called, by other wheels or pinions attached to the axis, such as have been described in page 53, No. 172.

SECTION XI.

Pneumatics.

240. Pneumatics treats of the nature, mechanical properties, and effects of air and similar fluids, which are distinguished by the name of uniform fluids.

What does Fig. 61 represent? How does this wheel differ from the overshot? 239. What is the breast wheel? How is it set in motion? What Fig. represents the breast wheel? To what is the motion given to the wheels which have been described, communicated? 240. Of what does Pneumatics treat?

241. The air which we breathe is an elastic fluid which surrounds the earth, and extends forty-five miles above its surface. It possesses many of the properties belonging to liquids in general, besides several others, the result, or, perhaps, the cause of its elasticity. Its specific gravity is eight hundred times less than that of water.*

242. Air, steam, vapor, gas, are all elastic fluids possessing the same mechanical properties.† Whatever, therefore, is stated in relation to air, belongs in common to all of these fluids.

243. Air and other similar fluids have weight, but their particles do not, under any circumstances, adhere together; or, in other words, they are influenced by gravity, but have no cohesive attraction.‡

244. Air has two principal properties, namely, gravity, or weight, and elasticity.

245. By the elasticity of the air is meant its power of increasing or diminishing in bulk, or extension, according as it is more or less compressed.§ It is this property which distinguishes the aeriform fluids from liquids.

* The air is necessary to animal and vegetable life, and to combustion. It is a very heterogeneous mixture, being filled with vapors of all kinds. It consists, however, of two principal ingredients called oxygen and nitrogen, or azote; of the former of which there are 28 parts, and of the latter, 72 in a hundred. The air is not visible, because it is perfectly transparent. It may be felt when it moves in the form of wind, or by swinging the hand rapidly backward and forward.

† The chemical properties of liquids, fluids, &c. are not treated in the sciences of Pneumatics, Hydraulics, or Hydrostatics, but belong peculiarly to the science of chemistry. They are not, therefore, described in this work.

‡ It has already been stated [*See No.* 61.] that heat insinuates itself between the particles of bodies, and forces them asunder, in opposition to the attraction of cohesion and of gravity; it, therefore, exerts its power against both the attraction of gravitation and the attraction of cohesion. But as the attraction of cohesion does not exist in fluids in the form of air, (or aeriform fluids) the expansive power of heat has nothing to contend with but gravity. Any increase of temperature, therefore, expands an elastic fluid prodigiously, and a diminution of heat condenses it.

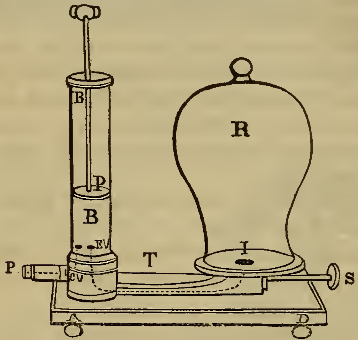
§ The terms "*rarefaction*," and "*rarified*" are applied to air when it is expanded; and "*condensation*," or "*condensed*" when it is compressed. It has already

241. What is the air which we breathe? How far does it extend above the surface of the earth? Does it possess properties common to liquids in general? How does its specific gravity compare with that of water? Of what two principal ingredients does the air consist? What is the proportion of these parts to each other? 242. What other fluids are named belonging to the class of elastic fluids? 243. Have the air, and other similar fluids, weight? With what power alone has heat to contend in aeriform fluids? 244. What two principal properties has the air? 245. What is meant by the elasticity of the air? How do the aeriform fluids differ from liquids? When is the air said to be rarified? When condensed?

246. The air pump is an instrument by means of which the air may be pumped or drawn from a vessel prepared for the purpose. The vessel is called a receiver, and is made of glass, in order that the effects of the removal of the air may be seen.

Illustration. Air pumps are made in various ways, and are of different constructions. Some have two barrels, (or, in other words, are double pumps,) and others only one. The difference between them will be presently explained. Fig. 64 represents a single barrel air pump,* used both for condensing and exhausting. A D is the stand or platform of the instrument, which is screwed down to the table by means of a clamp, underneath, which is not represented in the figure. R is the glass vessel or bulbed receiver from which the air is to be exhausted. P is a solid piston, accurately fitted to the bore of the cylinder, and H the handle by which it is moved. The dotted line, F, represents the communication between the receiver R and the barrel B; it is a tube through which the air, entering at the opening I, on the plate of the pump, passes into the barrel, through the exhausting valve E V. C V is the condensing valve, communicating with the barrel B by means of an aperture near E, and opening outwards through the condensing pipe P.

Fig. 64.



been stated [*See page* 22, *No.*82] that the air near the surface of the earth bears the weight of that which is above it. Being compressed, therefore, by the weight of that above it, it must exist in a condensed form near the surface of the earth, while in the upper regions of the atmosphere, where there is no pressure, it is highly rarified. This condensation, or pressure, is very similar to that of water at great depths in the sea. [*See No.* 207.]

* The air pump, described in this figure, is one of a number made by A. & D. Davis, of this city, by order of a special committee, for the Boston Schools. It has a piston of large size, being an inch and a half in calibre. The pneumatic instruments, mentioned in this section, belong to the same set, and are from the same manufacturer. There are several other manufactories of philosophical instruments, in the city, which deserve commendation, among which may be mentioned those of Mr. T. Claxton, and Mr. Chamberlin.

Is the air, near the surface of the earth, rare or dense? 246. What is the use of the air pump? What fig. represents an air pump? Explain the figure.

The operation of the pump is as follows: The piston P being drawn upwards by the handle H, the air in the receiver R, by its elasticity expanding, passes by the aperture I through the tube T, and through the exhausting valve E V into the barrel. On the descent of the piston the air cannot return through that valve, because the valve opens *upwards* only; it must, therefore, pass through the aperture by the side of the valve and through the condensing valve C V into the pipe P, where it passes out into the open air. It cannot return through the condensing valve C V, because that valve opens *outwards* only. By continuing this operation, every ascent and descent of the piston P must render the air within the receiver R more and more rare, until its elastic power is entirely exhausted. The receiver is then said to be exhausted; and although it still contains a small quantity of air, yet it is in so rare a state that the space within the receiver is considered a *vacuum.**

From the explanation which has been given of the operation of this air pump, it will readily be seen that by removing the receiver R and screwing any vessel to the pipe P, the air will be condensed in the vessel. Thus the pump is made to exhaust or to condense, without alteration.†

The double air pump differs from the single air pump in having two barrels and two pistons; which instead of being moved by the hand, are worked by means of a toothed wheel, playing in notches of the piston rods.

247. By means of the air pump the following facts are illustrated. *First*, That the air has weight. *Secondly*, that it is susceptible of almost unlimited expansion. *Thirdly*, that it can also be condensed, or crowded into much smaller dimensions than it naturally has.‡

* Properly speaking, a vacuum is a space entirely empty, having neither air nor any other substance in it. From the explanation now given of the operation of the air pump, it will be seen, that that instrument is incapable of producing a *perfect vacuum*. But the air within the receiver is so exceedingly rare, when thus exhausted, that, for all practical purposes, it may be considered a vacuum. The only mode of producing a perfect vacuum is by means of the Torricellian experiment, on the principle of the Barometer, which will be explained hereafter.

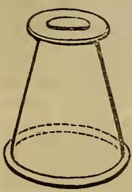
† The piston and valves of the air pump should be kept well oiled. All the brass work, in the Boston School set, being lackered need not be polished; but all those parts which come into contact with water should be wiped dry after they have been used.

‡ This property is not illustrated by common air pumps, but is exhibited by an instrument called a condensing syringe, or condenser. The peculiar construction of the air pump, belonging to the "Boston School set" of philosophical instruments, as has already been shown, adapts the instrument both for exhausting and condensing, and thereby supplies the place of a separate instrument for condensing. The condensing syringe is, in fact, nothing more than the air pump reversed, by which air is driven into any vessel instead of being drawn out The valve, therefore, opens inwards in respect to the vessel, instead of outwards, as the exhausting pump is constructed.

Explain the operation of the pump. What is meant by a vacuum? In what way can a perfect vacuum be produced? How does the double air pump differ from the single? What facts are illustrated by means of the air pump?

Experiments to be made with the air pump. 1. Place the glass receiver R, as represented in fig. 64, upon the pump plate, and exhaust the air from under it, by working the piston up and down. The receiver will adhere strongly to the plate. But if the air be re-admitted by turning the screw S, the receiver may easily be raised. This experiment shows the pressure of the atmosphere, caused by its weight.

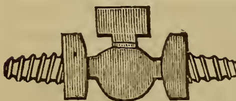
Fig. 65.



2. Fig. 65 represents the hand glass. It is, in fact, nothing more than a tumbler, open at both ends, with the top and bottom ground smooth, so as to fit the brass plate of the air pump. Put it upon the plate, and cover it closely with the palm of the hand, and work the pump. The air within the glass being thus exhausted, the hand will be pressed down by the weight of the air above it; and the pressure felt upon that portion of the hand over the glass will be equal to 14 or 15 pounds to every square inch. This experiment, likewise, shows the pressure of the air.

3. Place a small bladder, partly filled with air, and tightly closed, under the glass receiver, and, on working the pump, thus removing the air from around the bladder, the air within will gradually expand, and cause the bladder to appear full. On turning the screw S and re-admitting the air, the bladder will immediately resume its shrivelled appearance. The same effect may be produced on a dried apple, or raisin, if the skin be whole. This experiment shows the elasticity of the air.

Fig. 66.



4. Fig. 66 represents a stop cock, of which there are two, of different sizes, with a screw fitted to the aperture I in the brass plate, or to the pipe near the condensing valve c v in front of the pump. By inserting the stop cock into an india rubber bag, or fitting a bladder to it, and screwing it into the pipe in front, and working the pump, air will be condensed into it. When this is done, remove the bag or bladder to the screw in the brass plate, and place another bag on the condensing pipe. On working the instrument, the air will be conveyed from the full to the empty bag or bladder. Thus the pump is made to exhaust and condense at the same time.

5. Fig. 67 represents the elastic tube. Screw the elastic tube into the pump plate, and connect the other end by the stop cock, with the glass syphon, [*See Fig.* 59.] immersed in mercury. On working the pump the mercury will rise in the syphon to the

Fig. 67.

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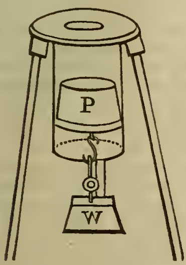
1. What is the first experiment mentioned, to be made with the air pump? What fig. represents it? What does this experiment show? 2. What is the second experiment? What fig. represents the hand glass? To what is the pressure, felt upon that portion of the hand over the glass, equal? What does this experiment show? 3. What is the third experiment mentioned? What does this experiment show? 4. What does fig. 66 represent? What is the fourth experiment? What may be shown from this? 5. What does fig. 67 represent? What is the fifth experiment?

height of more than twenty-eight inches, showing that the upward pressure of the atmosphere is equal to this height of mercury.*

6. With the elastic tube still attached to the air pump, and the syphon, as in the last experiment, the stop cock being open; stop the other end of the syphon with the finger—exhaust the air—then close the stop cock—now insert the end of the syphon, which is stopped with the finger, into a bowl of water, and remove the finger—the water will immediately fill the whole length of the syphon, and would rise thirty-three feet, were the syphon as long.

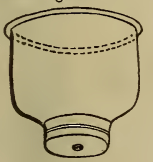
Fig. 68.



7. Fig. 68 represents the instrument for raisng a weight by the upward pressure of the air. It consists of a glass tube, of largé bore, set in a strong case or stand, supported by three legs. A piston is accurately fitted to the bore of the tube, and a hook is attached to the bottom of the piston from which weights are to be suspended. One end of the elastic tube is to be screwed to the plate of the pump, and the other end attached to the top of this instrument. The air being then exhausted from the tube, the weights will be raised the whole length of the glass. The number of pounds weight that can be raised by this instrument may be estimated by multiplying the number of square inches in the bottom of the piston, by fifteen. This experiment shows the upward pressure of the air.

8. Fig. 69 is a bell-shaped glass, covered with a piece of bladder, which is tied tightly around its neck. Thus prepared it may be screwed to the plate of the air pump, or connected with it by means of the elastic tube. On exhausting the air from the glass, the external pressure of the air on the bladder will burst it inwards with a loud explosion. The experiment may be reversed, and the bladder burst, by condensing air within the glass. For this purpose, transfer the glass or the elastic tube, connected with it, to the condensing tube P, and, on working the pump, the air will be condensed within the glass, and by its pressure burst the bladder outwards, with a loud explo-

Fig. 69.



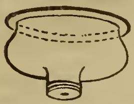
* This experiment furnishes a test of the power of the pump. Caution is necessary in disengaging the syphon from the flexible tube, or taking it out of the mercury. In all cases the thumb screw of the air pump should be turned, and air admitted before removing the syphon, &c., otherwise, the air, rushing in at the lower end of the syphon, will force the mercury violently into the air pump, and probably break the syphon.

What does this experiment show? 6. What is the sixth experiment? 7. What does fig. 68 represent? Of what does it consist? How is it used? How can the number of pounds weight, that can be raised by this instrument, be estimated? What does this experiment show? 8. What does fig. 69 represent? What experiments are mentioned in No. 8?

sion. The former experiment is the result of the gravity—the latter of the elasticity of the air.

9. Fig. 70 is a glass similar to the one represented in the last figure, covered with india rubber. The same experiments may be made with this as were mentioned in the last article, but with different results. Instead of bursting, the india rubber will be pressed inwards the whole depth of the glass, when the air is exhausted; and will swell outwards like an inflated bladder when the air is condensed in the glass.

Fig. 70.



10. Fig. 71 is called the guinea and feather drop. In most collections of philosophical apparatus this instrument consists of a tall receiver with brass shelves near the top, on which a guinea and a feather may be placed. The air being exhausted, and a screw on the top being turned, the shelves drop and cause the guinea and feather to fall together. This instrument is designed to show how falling bodies are retarded by the resistance of the air. When the air is within the receiver, the guinea will fall first, while the feather, being retarded by the resistance of the air, falls slowly; but when the air is exhausted they will both reach the bottom at the same moment. The instrument represented in the figure is the one belonging to "*the Boston School set*," and is of different construction. It consists of a large glass tube, sealed at one end, and fitted for the reception of the stop cock (*See fig.* 66.) at the other. A feather and a small piece of brass (in lieu of the guinea,) are enclosed in it. Before exhausting the air it should be turned several times to show that the heavy body (namely, the brass) will fall first. It should then be screwed to the plate of the pump, the air exhausted, and the stop cock closed. On removing it from the pump and turning it up, it will be seen that both the feather and the brass will fall together, and reach the bottom at the same time.

Fig. 71.

11. Fig. 72 represents the straight jet, which is a small brass tube. Fig. 73 is the fountain glass. The experiment with these instruments is designed to show the pressure of the atmosphere on the surface of liquids. Screw the stop cock to the plate of the air pump, then screw the straight jet into the stop cock, and the fountain glass over the jet to the cock. Having exhausted the air from the fountain glass, turn the stop cock, and removing it with the glass from the pump, and immersing it in a ves-

Fig. 72.

Fig. 73.

Of what is the first experiment the result? The second? 9. What does fig. 70 represent? How do the experiments, mentioned in No. 9, differ from those of No. 8. 10. What does fig. 71 represent? What is this instrument designed to show? When will the guinea fall first? When will they both fall at the same time? 11. What do figs. 72 and 73 represent? What are the experiments, made by this instrument, designed to show? What experiment is mentioned here?

sel of water, open the stop cock. The pressure of the air on the surface of the water will cause it to rush up into the glass like a fountain.

12. Fig. 74 represents the flask or glass vessel and scales for weighing air. Screw the stop cock to the flask, and, hanging it to the hook under the shorter scale, ascertain the weight of the flask while it is open, and, of course, filled with air—then, having screwed it into the pump plate, and exhausted the air, again weigh the flask. The difference between its present and former weight is the weight of the air that was contained in the flask.*

Fig. 74.

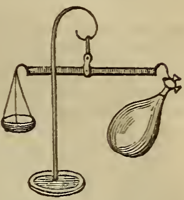
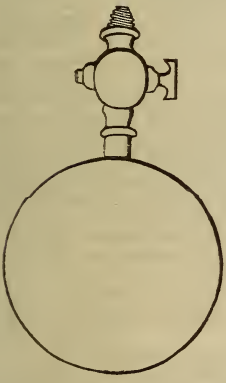
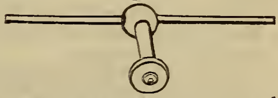


Fig. 75.



13. Fig. 75 is a hollow, brass globe, or condensing chamber, for condensing air. Having partly filled it with water and inserted the stop cock, screw it to P, the condensing pipe of the pump, and condense the air; then turn the stop cock to confine the air, and, removing the globe from the pump, insert the straight jet (Fig. 72) into the stop cock; and, on turning the cock, the pressure of the air within the globe will force the water out in a beautiful stream, and with great force.

Fig. 76.



The same experiment may be performed with the revolving jet represented in fig. 76. The water will form a beautiful circle in the air as it is forcibly ejected from the jet, and the tube will rapidly revolve.

* Condensed air may, likewise, be weighed in the brass globe, after being introduced as described in the next experiment. In weighing air, the temperature of the room must be observed, because heat rarifies it and renders it lighter; therefore the warmer the room in which the experiment is tried, the lighter the air will be.

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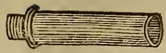
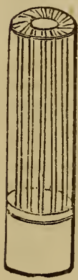
12. What does fig. 74 represent? What experiment is mentioned? How can condensed air be weighed? What is necessary to be observed in weighing air? 13. What does fig. 75 represent? What experiment is mentioned? What does fig. 76 represent?

Fig. 77.



14. Fig. 77 is a small brass cy - inder or gun barrel, with a screw fitted to the brass globe, designed to show the operation of an air gun.* Screw the brass globe, with the stop cock, to the condensing pipe of the air pump and condense the air. Turn the stop cock, remove the globe from the condensing pipe, and screw the gun barrel to the stop cock—put a lead shot, or paper ball, into the barrel, and quickly open the stop cock—the shot will be thrown with force across the room.

Fig. 78.



15. Fig. 78 represents the straight receiver.† Fill the straight receiver with water, and placing it on the plate of the air pump, cover it with the bulbed receiver, and exhaust the air. The air contained within the water will then rise in bubbles, and, escaping from the surface, present the appearance of boiling water.

16. With the two receivers, as in the last experiment, sink a piece of wood in the water, and, on exhausting the air from the water, the air will be seen issuing from the pores of the wood.

17. Fig. 79 represents the glass balloon. With the receiver, as in the last two experiments, place the balloon with the neck downwards upon the surface of the water. (It will, perhaps, be necessary to admit a little water into the balloon to make it stand in the water.) On exhausting the air, the air will be seen issuing from the balloon. The air being admitted into the receiver, the balloon will sink; or, again exhausting the air the balloon will rise. This experiment may be repeated at pleasure.

Fig. 79.

18. Ether, alcohol, and other distilled liquors, or boiling water, placed under the receiver, will appear to boil when the air is exhausted.

19. Place a lighted taper, cigar, or any other substance, that will produce smoke, under the receiver, and exhaust the air,—the light will be extinguished and the smoke will fall, instead of rising. If the air be readmitted the smoke will ascend.

* Condensed air, by its elastic force, will produce effects similar to gun-powder. Air guns have been constructed from which shot may be thrown with a force almost as great as that of gun-powder. With the air gun, a bullet may be made to perforate a board. With the brass globe and the cylinder or gunnel barrel, described in fig. 77, the operation of the air gun may easily be understood.

† This vessel properly belongs to the electrical apparatus, and for this reason it is coated with strips of tin foil, like a Leyden jar. It is used with the pneumatic

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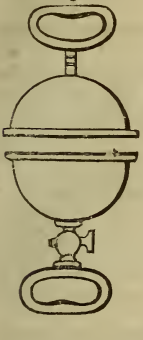
14. What does fig. 77 represent? What is its design? What is said, with regard to condensed air, in the note? What experiment is mentioned? 15. What does fig. 78 represent? What experiment is here mentioned? 16. What experiment is mentioned in No. 16. 17. What does fig 78 represent? What experiment is here mentioned? 18. What is stated in Nos. 18 and 19?

20. Fill the straight receiver with water, cover it closely with paper, and invert it—the paper will be held on by the upward pressure of the air, although it sustains the whole weight of the water.

Fig. 80.



21. Fig. 80 represents the Magdeburgh cups or hemispheres. They consist of two hollow brass cups, the edges of which are accurately fitted together. They each have a handle, to one of which the stop cock is fitted. The stop cock, being attached to one of the cups, is to be screwed to the plate of the air pump, and left open. Having joined the other cup to that on the pump, exhaust the air from within them, turn the stop cock to prevent its readmission, and screw the handle that had been removed to the stop cock. Two persons may then attempt to draw these cups asunder. It will be found that great power is required to separate them; but, on readmitting the air between them, by turning the cock, they will fall asunder by their own weight. When the air is exhausted from within them, the pressure of the surrounding air upon the outside keeps them united. This pressure, as has already been stated, is equal to a pressure of fifteen pounds on every square inch of the surface. Whence it follows that the larger the cups or hemispheres the more difficult it will be to separate them.

22. By means of a weight, sink a small bladder, partly filled with air, and tightly closed, in water contained in the straight receiver—cover it with the bulbed receiver, and exhaust the air—as the surrounding pressure is thus removed the air within the bladder will expand, and its specific gravity being thus diminished, it will rise. On re-admitting the air it will sink again.

23. If an animal be placed under the receiver, and the air exhausted, it will immediately droop, and if the air be not speedily readmitted it will die.

24. A simple and interesting experiment, connected with the science of chemistry, may thus be performed by means of the air pump. A watch glass, containing water, is placed over a small vessel containing sulphuric acid, and put under the bulbed receiver. When the air is exhausted, vapor will freely rise from the water, and be quickly absorbed by the acid. An intense degree of cold is thus produced, and the water will freeze.

In the above experiment if ether be used instead of the acid,

instruments in "the Boston School set," under the name of the straight receiver, on account of its small size, which allows the bulbed receiver to cover it. Economy suggests the application of each instrument to as many purposes as it can conveniently answer.

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20. What is stated in No. 20? 21. What does fig. 80 represent? What experiment is here mentioned? Does the size of the cups have any effect upon their separation? 22. What experiment is here mentioned? 23. What one is mentioned in this number? 24. What experiment, connected with the science of chemistry, is mentioned?

the ether will evaporate instead of the water, and in the process of evaporation, depriving the water of its heat, the water will freeze. These two experiments, apparently similar in effects, namely, the freezing of the water, depend upon two different principles which pertain to the science of chemistry.

The following experiments may be made with the syphon. [*See Fig.* 59.]

25. Screw the stop cock into the shorter end of the syphon, close the stop cock, and pour mercury or water into the longer side. The air contained in the shorter side will prevent the liquids from rising in the shorter side. But if the stop cock be opened so as to afford free passage outwards for the air, the fluids will rise to an equilibrium, that is, to equal height in both arms of the syphon.

26. With water or mercury in the syphon, and the stop cock open, turn the syphon so that the fluid will enter the shorter arm, and when that arm is filled up to the stop cock, close the stop cock to prevent the admission of the air: the syphon may then be turned in any direction and the fluid will not run out, on account of the pressure of the atmosphere against it. But if the stop cock be opened, the fluid will run out freely.

27. With a quantity of water in the balloon, (Fig. 79.) or a weight attached to it sufficient to render its specific gravity nearly the same with that of water, immerse it in a tall vessel full of water, and let it float on the surface. Cover the top of the vessel closely with Indiarubber, or any elastic covering. On pressing the covering with the hand, the balloon will immediately descend in the water, and when the pressure is removed it will again float about, rising or falling, or standing still, according to the pressure on the covering.

This experiment may be thus explained:—the pressure on the top of the vessel first condenses the air between the cover and the surface of the water—this condensation presses upon the water below, and as this pressure affects every portion of the water throughout its whole extent, the water, by its upward pressure, compresses the air within the balloon, and makes room for the ascent of more water into the balloon so as to alter the specific gravity of the balloon, and cause it to sink. As soon as the pressure ceases, the elasticity of the air in the balloon drives out the lately entered water, and restoring the former lightness to the balloon causes it to rise. If, in the commencement of this experiment, the balloon be made to have a specific gravity too near that of water, it will not rise of itself, after once reaching the bottom, because the pressure of the water then above it will perpetuate the condensation of the air which caused it to descend. It may even then, however, be made to rise, if the perpendicular height of the water above it be diminished by inclining the vessel to one side.

What will be the effect if ether be used instead of the acid? 25. What experiment, made with the syphon, is mentioned in No. 25? 26? 27? How would you explain this experiment? What will be the effect if the balloon, in the commencement of this experiment, be made to have a specific gravity too near that of water? Why will it not rise? How can it be made to rise? What does this experiment prove?

This experiment proves many things; namely:

First. The materiality of air, by the pressure of the hand on the top being communicated to the water below through the air in the upper part of the vessel.

Secondly. The compressibility of air, by what happens in the globe before it descends.

Thirdly. The elasticity, or elastic force of air, when the water is expelled from the globe, on removing the pressure.

Fourthly. The lightness of air, in the buoyancy of the globe.

Fifthly. It shows that *the pressure of a liquid is exerted in all directions*, because the effects happen in whatever position the jar be held.

Sixthly. It shows *that pressure is as the depth*, because less pressure of the hand is required, the farther the globe has descended in the water.

Seventhly. It exemplifies many circumstances of *fluid support.* A person, therefore, who is familiar with this experiment,* and can explain it, has learned the principal truths of hydrostatics and pneumatics.

248. Air may become a mechanical agent by means of its four properties, weight, inertia, fluidity, (or power of transmitting pressure,) and its elasticity.

249. The pressure of the air, (as has already been stated) caused by its gravity or weight, is equal to fifteen pounds on every square inch of any surface; hence it is calculated that a man of common stature has to sustain a weight of about fourteen tons of air. The equality of the pressure on every part of his body prevents his being injured by this immense weight; and the air contained within the body and its pores, also counterbalances the weight of the external air. If this

* On the same principle with the balloon, described in this experiment, several images of glass, hollow within, and each having a small opening at the heel by which water may pass in and out, may be made to manœuvre in a vessel of water. Place them in a vessel in the same manner with the balloon, but by allowing different quantities of water to enter the apertures in the images, cause them to differ a little from one another in specific gravity. Then, when a pressure is exerted on the cover, the heaviest will descend first, and the others follow in the order of their specific gravity; and they will stop or return to the surface in reverse order, when the pressure ceases. A person exhibiting these figures to spectators, who do not understand them, while appearing carelessly to rest his hand on the cover of the vessel, seems to have the power of ordering their movements by his will. If the vessel, containing the figures, be inverted, and the cover be placed over a hole in the table, through which, unobserved, pressure can be made by a rod rising through the hole, and obeying the foot of the exhibiter, the most surprising evolutions may be produced among the figures, in perfect obedience to the word of command.

First? Secondly? Thirdly? Fourthly? Fifthly? Sixthly? Seventhly? What experiment is mentioned in the note? 248. How may air become a mechanical agent? 249. To what is the pressure of the air, on every square inch, equal? What weight of air does a common sized man sustain? Why does not this weight injure him?

external pressure were removed, the air within the body, meeting with no external pressure to restrain its elasticity, would burst the parts which confine it, and destroy life. This pressure is proved by experiments numbers 2, 8, and 21, pages 82, 83, and 87.

250. A vacuum is a space from which the air and every other substance has been removed.

251. The resistance which light bodies meet from the air, causes them to fall slowly, while heavy bodies, more readily overcoming this resistance, fall rapidly. This is proved by experiment number 10, page 84.

252. When the external pressure is removed from any portion of confined air, it will immediately expand, and to this expansion there are no known limits. See experiment number 3, page 82.

253. A column of air reaching to the top of the atmosphere, the base of which is a square inch, weighs fifteen pounds, when the air is heaviest. (*See No.* 246.) Therefore, as all fluids press equally, in all directions, every inch of our bodies sustains a weight of fifteen pounds. The exact pressure that any individual sustains may, therefore, be ascertained by finding the number of square inches there are on the surface of his body, and multiplying it by fifteen. In like manner, the weight of the whole atmosphere * may be ascertained by finding the number of square inches there are on the surface of the globe, and multiplying the same by fifteen. In this way it has been ascertained that the weight of the whole atmosphere is more than five thousand billions of tons.

* The exact height, to which the atmosphere extends, has never been accurately ascertained; but it ceases to reflect the sun's rays at a greater height than forty-five miles. It has been computed that the weight of the whole atmosphere is equal to that of a globe of lead, sixty miles in diameter.

What would be the effect if this external pressure were removed? 250. What is a vacuum? 251. Why do light bodies fall more slowly than heavy? How is this proved? 252. What will be the effect if the external pressure be removed from any portion of confined air? Are there any known limits to this extension? 253. What is the weight of a column of air, the base of which is a square inch, reaching to the top of the atmosphere, when the air is heaviest? What weight does every inch of our bodies sustain? How can the weight of the whole atmosphere be ascertained? Has the exact height to which the atmosphere extends been accurately ascertained? At what height does it cease to reflect the sun's rays. To what is the computed weight of the atmosphere equal?

254. The air consists of particles possessing the inherent properties of matter. It, therefore, has the property of impenetrability, (*See No's.* 23 *and* 24.) like all other substances.

Illustration. If a tube, closed at one end, or an inverted tumbler, be inserted at its open end, in a vessel of water, the water will not rise in the tube or tumbler, to a level with the water in the vessel, on account of the impenetrability of the air within the tube. But if the tube be open at both ends, the water will rise, because the air can escape through the upper end. It is on this principle that the diving bell (or the diver's bell, as it is sometimes called,) is constructed.

Fig. 81.

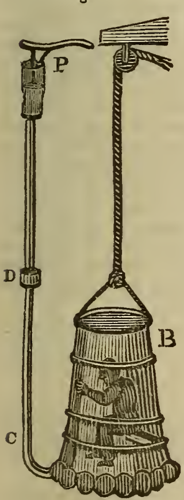

Fig. 81 represents a diving bell. It consists of a large heavy vessel, formed like a bell, (but may be made of any other shape,) with the mouth open. It descends into the water with its mouth downwards. The air within it having no outlet is compelled, by the order of specific gravities, to ascend in the bell, and thus (as water and air cannot occupy the same space at the same time,) prevents the water from rising in the bell A person, therefore, may descend with safety in the bell to a great depth in the sea, and thus recover valuable articles that have been lost. A constant supply of fresh air is sent down, either by means of barrels, or by a forcing pump similar to the condenser of the air pump. In the fig., B represents the bell with the diver in it. C is a bent metallic tube attached to one side and reaching the air within; and P is the forcing pump through which air is forced into the bell. The forcing pump is attached to the tube by a joint at D.

When the bell descends to a great depth, the pressure of the water condenses the air within the bell, and causes the water to ascend in the bell. This is forced out by constant accessions of fresh air, supplied as above mentioned. Great care must be taken that a constant supply of fresh air is sent down, otherwise the lives of those within the bell will be endangered. The heated and impure air is allowed to escape through a stop cock in the upper part of the bell.

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254. Of what does the air consist? What follows from this? What illustration of this is given? Upon what principle is the diving bell constructed? What fig. represents the diving bell? Why does not the water rise in the bell? Explain the figure.

255. The Barometer, or weather glass,* is an instrument to measure the weight or pressure of the atmosphere, and foretel the variations of the weather.

256. The Thermometer† is an instrument to measure the heat of the air.

257. The Hygrometer ‡ is an instrument to measure the degree of moisture in the air.

Fig. 82.

Fig. 82 represents a barometer. It consists of a long glass tube, about thirty-three inches in length, closed at the upper end and filled with mercury. The tube is then inverted in a cup, or leather bag, of mercury, on which the pressure of the atmosphere is exerted. As the tube is closed at the top it is evident that the mercury cannot descend in the tube without producing a vacuum.§ The pressure of the atmosphere (which is capable of supporting a column of mercury of about 28 or 30 inches in height) prevents the descent of the mercury; and the instrument, thus constructed, becomes an implement for ascertaining the weight of the atmosphere. As the air varies in weight or pressure, it must, of course, influence the mercury in the tube, which will rise or fall in exact proportion with the pressure. When the air is thin and light, the pressure is less, and the mercury will descend; and when the air is dense and heavy, the mercury will rise. At the side of the tube there is a scale, marked inches and tenths of an inch, to note the rise and fall of the mercury.||

* The word Barometer signifies *the measure of weight.*

† The word Thermometer means *the measure of heat.*

‡ The word Hygrometer means *the measure of moisture.*

§ The vacuum produced by inverting a tube of mercury thus closed at the top, is called the Torricellian vacuum, from Torricelli, an Italian philosopher, who first discovered this means of producing it. This method produces the most perfect vacuum that can be formed.

|| Any other fluid may be used as well as mercury, provided the length of the tube be extended in proportion to the specific gravity of the fluid. Thus, a tube filled with water must be 33 feet long, because the atmosphere will support a column of water of that height. Mercury is used, therefore, in the construction of the barometer, because it does not require so long a tube as any other fluid. It may here be remarked that the air is the heaviest, and that, consequently, the

255. What is a barometer? What does the word barometer mean? 256. What is a thermometer? What does the word thermometer mean? 257. What is a hygrometer? What does the word hygrometer mean? What figure represents a barometer? Explain its construction. What is said, in the note, with regard to the vacuum produced by inverting a tube of mercury thus closed at the top? What height of mercury is the pressure of the atmosphere capable of sustaining? What effect has the pressure of the atmosphere on the mercury in the tube? In what proportion does the mercury rise and fall? In what way can barometers be made of other fluids? Why is mercury used in preference to any other fluid? Is the air heaviest, in wet or dry weather?

258. The pressure of the atmosphere on the mercury, in the bag or cup of a barometer, being exerted on the principle of the equilibrium of fluids, (*See number* 201,) it must vary according to the situation in which the barometer is placed. For this reason it will be the greatest in valleys and low situations, and least on the top of high mountains. Hence, the barometer is often used to ascertain the height of mountains, and other places above the level of the sea.*

Fig. 83.

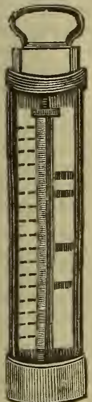

Fig. 83 represents a thermometer. (*See No.* 256.) In appearance it resembles a barometer, but it is constructed on a different principle, and for a different purpose. It consists of a capillary tube, closed at the top, and terminated with a bulb, which is filled with mercury.† As heat expands and cold contracts most substances, it follows that in warm weather the mercury must be expanded and will rise in the tube, and that in cold weather it will contract and sink. Hence the instrument becomes a correct measure for the heat and cold of the air. A scale‡ is placed at the side of the tube, to mark the degree of heat or cold, as it is indicated by the rise and fall of the mercury in the capillary tube.

mercury will rise highest in dry weather. In wet weather the dampness renders the air less salubrious, and it appears, therefore, more heavy then, although it is, in fact, much lighter.

* As the air diminishes in density, upwards, it follows that it must be more rare upon a hill than on a plain. In very elevated situations it is so rare that it is scarcely fit for respiration, or breathing; and the expansion which takes place in the more dense air contained within the body is often painful: it occasions distension, and sometimes causes the bursting of the smaller blood-vessels, in the nose and ears. Besides, in such situations, we are more exposed both to heat and cold; for, though the atmosphere is itself transparent, its lower regions abound with vapors and exhalations from the earth, which float in it, and act, in some degree, as a covering, which preserves us equally from the intensity of the sun's rays, and from the severity of the cold.

† Any other liquid which is expanded by heat and contracted by cold, such as spirits of wine, &c. will answer as well as mercury.

‡ There are several different scales applied to the thermometer, of which those of Fahrenheit, Reaumur, Delisle and Celsius are the principal. The thermometer, in common use in this country, is graduated by Fahrenheit's scale, which, commencing with 0, or zero, extends upwards to 212°, the boiling point of water, and downwards to 20 or 30 degrees. The scales of Reaumur and Celsius fix zero at the freezing point of water; and that of Delisle at the boiling point.

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258. On what principle is the pressure of the atmosphere on the mercury, in the cup of a barometer, exerted? What follows from this? For what other purpose, beside measuring the pressure of the atmosphere and foretelling the variations of the weather, is the barometer used? Is the air the more dense, at the surface of the earth or upon a hill? What figure represents a thermometer? Explain its construction. What effect have heat and cold on most substances? What follows from this? Whose scale is generally used in this country?

The hygrometer, for measuring the degree of moisture in the air,* may be constructed of any thing which contracts and expands by the moisture and dryness of the atmosphere—such as most kinds of wood; catgut, twisted cord, the beard of wild oats, &c.

259. The pressure of the atmosphere on the surface of a well, or any other portion of water, is the means by which water is raised by the common pump. By the act of pumping, the pressure of the atmosphere is removed from the water within the body of the pump, and the water, consequently, will rise.

Fig. 84 represents the common pump, called the sucking pump. The body consists of a large tube, or pipe, the lower end of which is to be immersed in the water which it is designed to raise. P is the piston, v a valve in the piston, which, opening upwards, admits the water to rise through it, but prevents its return. Y is a similar valve in the body of the pump, below the piston. When the pump is not in action the valves are closed by their own weight; but when the piston is raised it draws up the column of water which rested upon it, producing a vacuum between the piston and the lower valve Y. The water below, immediately rushes through the lower valve, and fills the vacuum. When the piston descends a second time, the water in the body of the pump passes through the valve v, and on the ascent of the piston is lifted† up by the piston, and a vacu-

* By the action of the sun's heat upon the surface of the earth, whether land or water, immense quantities of vapor are raised into the atmosphere, supplying materials for all the water which is deposited again in the various forms of dew, fog, rain, snow and hail. Experiments have been made to show the quantity of moisture thus raised from the ground by the heat of the sun. Dr. Watson found that an acre of ground apparently dry, and burnt up by the sun, dispersed into the air sixteen hundred gallons of water in the space of twelve hours. His experiment was thus made: he put a glass, mouth downwards, on a grass plot, on which it had not rained for above a month. In less than two minutes the inside was covered with vapor; and in half an hour drops began to trickle down its inside. The mouth of the glass was twenty square inches. There are 1296 square inches in a square yard, and 4840 in an acre. When the glass had stood a quarter of an hour, he wiped it with a piece of muslin, the weight of which had been previously ascertained. When the glass had been wiped dry, he again weighed the muslin, and found that its weight had been increased six grains, by the water collected from twenty square inches of earth; a quantity equal to 1600 gallons, from an acre, in twenty-four hours. Another experiment, after rain had fallen, gave a much larger quantity. [See *Illustration 2d, page* 12.]

When the atmosphere is colder than the earth, the vapor, which arises from the ground, or a body of water, is condensed and becomes visible. This is the way that fog is produced. When the earth is colder than the atmosphere, the moisture in the atmosphere condenses in the form of dew, on the ground, or other surfaces.

Clouds are nothing more than vapor, condensed by the cold of the upper regions of the atmosphere.

Rain is produced by the sudden cooling of large quantities of watery vapor.

Snow and hail are produced in a similar manner, and differ from rain, only, by the degree of cold which produces them.

† This is the reason why this kind of pump is sometimes called '*the lifting pump.*'

For what is the hygrometer used? Of what kind of substances may it be constructed? What experiment is given in the note to show the quantity of moisture raised from the ground by the heat of the sun? How is fog produced? What are clouds? How is rain produced? How are snow and hail produced? 259. By what means is water raised in the common pump? How is the pressure removed? What fig. represents the common pump? Explain it. Why is this sometimes called the lifting pump?

Fig. 84.

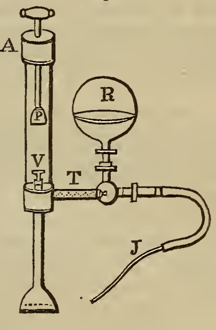
um is again formed below, which is immediately filled by the water rushing through the lower valve Y. In this manner the body of the pump is filled with water, until it reaches the spout S, where it runs out in an interrupted stream.*

260. Water can be raised by the common pump only about 32 feet, because the weight or pressure of the atmosphere is equal to the weight of a column of water of that height only.

261. The forcing pump differs from the common pump in having a forcing power added to raise the water to any desired height.

Fig. 85 represents the forcing pump. The body and lower valve V are similar to those in the common pump. The piston P has no valve, but is solid; when, therefore, the vacuum is produced above the lower valve, the water on the descent of the piston is forced through the tube into the reservoir or air vessel R, where it compresses the air above it. The air, by its elasticity, forces the water out through the jet J in a continued stream and with great force. It is on this principle that fire engines are constructed.

Fig. 85.



Sometimes a pipe with a valve in it is substituted for the air vessel; the water is then thrown out in a continued stream, but not with so much force.

262. Wind is a current of air put in motion.†

* The handle of a common pump is a lever of the first kind, the shorter arm of which is connected with the piston.* When the handle is pressed down, the piston ascends. The valves, and the parts which contain them, are, in common language, called "*boxes*."

† There are two ways in which the motion of the air may be explained. It may be considered as an absolute motion of the air, rarified by heat and condensed by cold—or it may be only an apparent motion, caused by the superior velocity of the earth in its daily revolution.

Which of the mechanical powers is the handle of the pump? 260. How high can water be raised by the common pump? Why? 261. How does the forcing pump differ from the common pump? What figure represents the forcing pump? Explain it. 262. What is wind? In what two ways may the motion of the air be explained?

Explanation. When any portion of the atmosphere is heated, it becomes rarified, its specific gravity is diminished, and it consequently rises. The adjacent portions immediately rush into its place to restore the equilibrium. This motion produces a current which rushes into the rarified spot from all directions. This is what we call wind. The portions north of the rarified spot rush downwards, producing a North wind; those to the south rush upwards, producing a South wind; while those to the East and West, in like manner, form currents moving in opposite directions. At the rarified spot, agitated as it is by winds from all directions, turbulent and boisterous weather, whirlwinds, hurricanes, rain, thunder and lightning prevail. This kind of weather occurs most frequently in the torrid zone, where the heat is greatest. The air being more rarified there than in any other part of the globe, is lighter, and, consequently, ascends; that about the polar regions is continually flowing from the poles to the equator, to restore the equilibrium; while the air rising from the equator flows in an upper current towards the poles, so that the polar regions may not be exhausted.* A regular east wind prevails about the equator, caused by the rarefaction of the air produced by the sun in his daily course from east to west. This wind, combining with that from the poles, causes a constant north-east wind, for about thirty degrees north of the equator, and a south-east wind at the same distance south of the equator.

* From what has now been said, it appears that there is a circulation of air in the atmosphere ; the air in the lower strata flowing from the poles to the equator ; and in the upper strata flowing back from the equator to the poles. It may here be remarked that the periodical winds are more regular at sea than on the land ; and the reason of this is that the land reflects into the atmosphere a much greater quantity of the sun's rays than the water ; therefore, that part of the atmosphere which is over the land is more heated and rarified than that which is over the sea : this occasions the wind to set in upon the land, as we find it regularly does on the coast of Guinea and other countries in the torrid zone. There are certain winds called trade-winds, the theory of which may easily be explained, on the principle of rarefaction, affected as it is by the relative position of the different parts of the earth with the sun, at different seasons of the year and at various parts of the day. A knowledge of the laws, by which these winds are controlled, is of importance to the mariner. When the position of the sun, with respect to the different positions of the earth, at the different seasons of the year is understood, it will be seen that they all depend upon the same principle. The reason that the wind generally subsides at the going down of the sun is, that the rarefaction of the air, in the particular spot which produces the wind, diminishes as the sun declines, and consequently the force of the wind abates. The great variety of winds in the temperate zones is thus explained. The air is an exceedingly elastic fluid, yielding to the slightest pressure ; the agitations in it, therefore, caused by the regular winds, whose causes have been explained, must extend every way to a great distance ; and the air, therefore, in all climates will suffer more or less perturbation,

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Explain the manner in which the air is put in motion. How are the north, south, east, and west winds produced? What kind of weather prevails at the rarified spot? Where does this kind of weather occur most frequently? What causes a regular east wind to prevail about the equator? Why are the periodical winds more regular at sea than on the land? How would you account for the winds called trade-winds monsoons, &c. What is the reason that the wind generally subsides at the going down of the sun? How can the great variety of winds, in the temperate zones, be explained?

SECTION XII.

Acoustics.

263. Acoustics is the science which treats of the nature and laws of sound. It includes the theory of musical concord or harmony.

264. Sound is caused by a tremulous or vibratory motion of the air.

Illustration. If a bell be rung under an exhausted receiver, no sound can be heard from it; but when the air is admitted to surround the bell, the vibrations immediately produce sound.

Again, if the experiment be made by inclosing the bell in a small receiver, full of air, and placing that under another receiver, from which the air can be withdrawn, though the bell, when struck, must then produce sound, as usual, yet it will not be heard if the outer receiver be well exhausted, and care be taken to prevent the vibrations from being communicated through any solid part of the apparatus; because there is no medium through which the vibrations of the bell, in the smaller receiver, can be communicated to the ear.

265. Sounds are louder when the air surrounding the sonorous body is dense, than when it is in a rarified state.

For this reason the sound of a bell is louder in cold than in warm weather; and sound of any kind is transmitted to a greater distance in cold, clear weather, than in a warm sultry day. On the tops of mountains, &c. where the air is rare, the human voice can be heard only at the distance of a few rods; and the firing of a gun produces a sound scarcely louder than the cracking of a whip.

according to the situation of the country, the position of mountains, valleys, and a variety of other causes. Hence every climate must be liable to variable winds. The *quality* of winds is affected by the countries over which they pass; and they are sometimes rendered pestilential by the heat of deserts, or the putrid exhalations of marshes and lakes. Thus, from the deserts of Africa, Arabia, and the neighboring countries, a hot wind blows, called *Samiel* or *Simoom*, which sometimes produces instant death. A similar wind blows from the desert of Sahara, upon the western coast of Africa, called the *Harmattan*, producing a dryness and heat which is almost insupportable, scorching like the blasts of a furnace.

By what is the quality of winds affected? What is that wind called which blows from the deserts of Arabia and Africa? What is that called which blows from the desert of Sahara? 263. What is that science called which treats of the nature and laws of sound? What does it include? 264. What causes sound? What illustrations are given to prove this? 265. In what proportion are sounds loud or faint? Why does a bell sound louder in cold than in warm weather? Why is sound fainter on the top of a mountain, than nearer the surface of the earth?

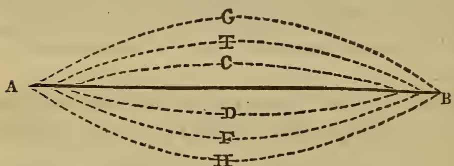
266. Sonorous bodies are those which produce clear, distinct, regular and durable sounds, such as a bell, a drum, wind instruments, musical strings and glasses. These vibrations can be communicated to a distance not only through the air, but also through liquids and solid bodies.

267. Bodies owe their sonorous property to their elasticity.*

268. The sound produced by a musical string is caused by its vibrations; and the height or depth of the tone depends upon the rapidity of these vibrations. Long strings vibrate with less rapidity than short ones, and for this reason the low tones in a musical instrument proceed from the long strings, and the high tones from the short ones.

Illustration. Fig. 86, A B represents a musical string. If it be drawn up to G, its elasticity will not only carry it back again, but will give it a momentum which will carry it to H, from whence it will successively return to T, F, C, D, &c. until the resistance of the air entirely destroys its motion.

Fig. 86.



The vibrations of a sonorous body gives a tremulous motion to the air around it, similar to the motion communicated to smooth water when a stone is thrown into it.

269. The science of harmony is founded on the relation which the vibrations of sonorous bodies have to each other. Thus when the vibrations of one string are double those of another, the chord of an octave is produced. If the vibrations of two strings are as two to

* Although it is undoubtedly the case that all sonorous bodies are elastic, it is not to be inferred that all elastic bodies are sonorous.

266. What are sonorous bodies? 267. To what do sonorous bodies owe their sonorous property? Are all elastic bodies sonorous? 268. What causes the sound produced by a musical string? Upon what does the height and depth of the tone depend? Which strings, in a musical instrument, produce the low tones? Why? Explain fig. 86. 269. Upon what is the science of harmony founded? How is the chord of an octave produced?

three, the chord of a fifth is produced.* When the vibrations of two strings frequently coincide, they produce a musical chord; and when the coincidence of the vibrations is seldom, a discord is produced.

270. The quality of the sound produced by strings depends upon their length, their thickness or weight, and their degree of tension. The quality of the sound produced by wind instruments depends upon their size, their length, and hollow diameters. Long and large strings, when loose, produce the lowest tones; but different tones may be produced from the same string, according to the degree of tension, or the tightness with which it is drawn. Large wind instruments, also, produce the lowest tones; and different tones may be produced from the same instrument, according to the distance of the aperture, for the escape of the wind, from the aperture where it enters; or, which is the same thing, the length of that portion of the instrument which is struck by the air. (*See Note to No.* 264.)

271. The quality of the sound of all musical instruments is affected, in some degree, by the changes in the temperature and specific gravity of the atmosphere, or the air in the room. As heat expands and cold contracts the materials of which the instrument is made, it follows that the strings will have a greater degree of tension, and that pipes and other wind instruments will be contracted, or shortened in cold weather. For this reason most musical instruments are higher in tone, (or sharper,) in winter, or cold weather, and lower in tone, (or more flat) in summer, or in warm weather.

* When music is made by the use of strings the air is struck by the body, and the sound is caused by the vibrations; when it is made by pipes, the body is struck by the air; but as action and reaction are equal, the effect is the same in both cases.

How is the chord of a fifth produced? How is a musical chord produced? A discord? 270. Upon what does the quality of the sound, produced by strings, depend? Upon what does that produced by wind instruments depend? What strings produce the lowest tones? How may different tones be produced from the same string? How may different tones be produced from the same wind instrument? 271. What, in some degree, affects the quality of the sound of all musical instruments? What effect has heat and cold on the materials of which the instrument is made? What follows from this? Why are most musical instruments higher in tone, or sharper, in cold weather?

272. Sound is communicated more rapidly and with greater power through solid bodies, than through the air, or fluids. It is conducted by water about four times quicker than by air, and by solids about twice as rapidly as by water.

If a person lay his head on a long piece of timber, he can hear the scratch of a pin at the other end, while it could not be heard through the air.

By placing the ear against a long, dry, brick wall, and causing a person to strike it once with a hammer, the sound will be heard *twice*, because the wall will convey it with greater rapidity than the air, though each will bring it to the ear.

The Stethescope is an instrument depending on the power of solid bodies to convey sound. It consists of a wooden cylinder, one end of which is applied firmly to the breast, while the other end is brought to the ear. By this means the action of the lungs and other internal parts of the human body may be distinctly heard. The instrument, therefore, becomes useful in the hands of a skilful physician to ascertain the state of the internal organs.

273. Sound, passing through the air, moves at the rate of 1142 feet in a second of time. This is the case with all kinds of sound. The softest whisper flies as fast as the loudest thunder, and the force or direction of the wind makes but slight difference in its velocity.

This uniform velocity of sound enables us to determine the distance of an object from which it proceeds. If, for instance, the light of a gun, fired at sea, is seen a half of a minute before the report is heard, the vessel must be at the distance of six miles and a half. In the same manner the distance of a thunder cloud may be ascertained by counting the seconds between the appearance of the lightning and the noise of the thunder, and multiplying them by 1142 feet.

274. An echo is produced by the vibrations of the air meeting a hard and regular surface, such as a wall, a rock, mountain, &c. and being reflected back to the ear, thus producing the same sound a second and sometimes a third and fourth time.*

* From this it is evident that no echo can be heard at sea, or on an extensive plain ; because there is no object there to reflect the sound. An echo is heard only

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272. Through which is sound communicated more rapidly, and with greater power, through solid bodies or the air? How fast is it conducted by water? How fast by solids? What examples are given to show that sound is communicated more rapidly through solid bodies than the air or fluids? What is a stethescope? Of what does it consist? For what is it used? 273 How fast does sound move? Does the force or direction of the wind make any difference in its velocity? What advantage results from this uniform velocity of sound? How can the distance of a thunder cloud be ascertained? 274. How is an echo produced?

275. Speaking trumpets are constructed on the principle of the reflection of sound.

The voice, instead of being diffused in the open air, is confined within the trumpet; and the vibrations which spread and fall against the sides of the instrument are reflected according to the angle of incidence, and fall in the direction of the vibrations which proceed straight forward. The whole of the vibrations are thus collected into a focus; and if the ear be situated in or near that spot, the sound is prodigiously increased.

Hearing trumpets, or the trumpets used by deaf persons, are, also, constructed on the same principle; but as the voice enters the large end of the trumpet, instead of the small one, it is not so much confined, nor so much increased.

The musical instrument called the trumpet acts, also, on the same principle with the speaking trumpet, so far as its form tends to increase the sound.*

276. Sound, like light, after it has been reflected from several places may be collected into one point, as a focus, where it will be more audible than in any other part; and on this principle whispering galleries may be constructed.

The famous whispering gallery in the dome of St. Paul's church, in London, is constructed on this principle. Persons at very remote parts of the building can carry on a conversation in a soft whisper,

when a person stands in such a situation as to hear both the original and the reflected sound. The pupil will doubtless recollect what has been said in mechanics with respect to the angles of incidence and reflection. Sound (as well as light, as will be explained under the head of optics) is communicated and reflected by the same law, namely, that the angles of incidence and reflection are always equal. It is not difficult, therefore, to ascertain the direction in which sound will proceed, whether it be direct or reflected. It is related of Dionysius, the tyrant of Sicily, that he had a dungeon (called the ear of Dionysius) in which the roof was so constructed as to collect the words and even the whispers of the prisoners confined therein, and direct them along a hidden conductor to the place where he sat to listen; and thus he became acquainted with the most secret expressions of his unhappy victims.

* The smooth and polished surface of the interior parts of certain kind of shells, particularly if they are spiral or undulating, fit them to collect and reflect the various sounds which are taking place in the vicinity. Hence the Cyprias, the Nautilus, and some other shells, when held near or in the ear, give a continued sound which resembles the roar of the distant ocean.

Why cannot an echo be heard at sea or on an extensive plain? How must a person stand in order to hear an echo? By what law is sound communicated and reflected? What anecdote is related of Dionysius? 275. Upon what principle are speaking trumpets constructed? Explain the manner in which the air is reflected. Upon what principle are hearing trumpets constructed? How far does the musical instrument, called the trumpet, act upon the principle of the speaking trumpet? How can the continued sound, given by some shells when held near the ear, be explained? 276. Upon what principle may whispering galleries be constructed?

which will be distinctly audible to one another, while others in the building cannot hear it; and the ticking of a watch may be heard from side to side.

277. Sounds can be conveyed to a much greater distance through continuous tubes than through the open air.

The tubes used to convey sounds are called acoustic tubes. They are much used in public houses, stores, counting rooms, &c. to convey communications from one room to another.

278. The quality of sound is affected by the furniture of a room, particularly the softer kinds, such as curtains, carpets, &c., because having little elasticity they present surfaces unfavorable to vibrations.

For this reason, music always sounds better in rooms with bare walls, without carpets, and without curtains. For the same reason a crowded audience increases the difficulty of speaking.

As a general rule, it may be stated that plane and smooth surfaces reflect sound without dispersing it, convex surfaces disperse it, and concave surfaces collect it.

279. The air is a better conductor of sound when it is humid than when it is dry.

A bell can be more distinctly heard just before a rain; and sound is heard better in the night than in the day, because the air is generally more damp in the night.

The distance to which sound may be heard, depends upon various circumstances, on which no definite calculations can be predicated. Volcanoes, among the Andes, in South America, have been heard at the distance of three hundred miles—naval engagements have been heard two hundred, and even the watch word, "*all's well*," pronounced by the unassisted human voice, has been heard from Old to New Gibraltar, a distance of twelve miles.

280. The sound of the human voice is produced by the vibration of two delicate membranes, situated at the top of the windpipe, and between which the air from the lungs passes. The tones are varied from grave to acute, by opening or contracting the passage; and they are regulated by the muscles belonging to the throat, by the tongue and by the cheeks.

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277. In what way can sounds be conveyed to a much greater distance than through the air? What are the tubes, used to convey sounds, called? 278. Why do the softer kinds of furniture, in a room, affect the quality of the sound? What general rule is given with regard to the reflection of sound? 279. Is the air a better conductor when it is humid or when it is dry? Why can a sound be heard better in the night than in the day? 280. How is the sound of the human voice produced? How are the tones varied and regulated?

The management of the voice depends much upon cultivation; and although many persons can both speak and sing with ease, and with great power, without much attention to its culture, yet it is found that those who cultivate their voices by use, acquire a degree of flexibility and ease in its management, which, in great measure, supplies the deficiency of nature.*

281. Ventriloquism † is the art of speaking in such a manner as to cause the voice to appear to proceed from a distance.

The art of ventriloquism was not unknown to the ancients; and it is supposed by some authors that the famous responses of the oracles, at Delphi, at Ephesus, &c. were delivered by persons who possessed this faculty. There is no doubt that many apparently wonderful pieces of deception, which, in the days of superstition and ignorance, were considered as little short of miracles, were performed by means of ventriloquism. Thus houses have been made to appear haunted, voices have been heard from tombs, and the dead have been made to appear to speak, to the great dismay of the neighborhood, by means of this wonderful art.

Ventriloquism is, without doubt, in great measure the gift of na-

* The reader is referred to Dr. Rush's very valuable work on the Philosophy of the Human Voice, for plain and practical instructions on this subject. Dr. Barber's Grammar of Elocution, and Parker's Progressive Exercises in Rhetorical Reading, likewise contain the same instructions, in a practical form. To the work of Dr. Rush, both of the latter mentioned works are largely indebted.

† The word ventriloquism literally means "*speaking from the belly*," and it is so defined in Chambers' Dictionary of Arts and Sciences. The ventriloquist, by a singular management of the voice, seems to have it in his power "*to throw his voice*" in any direction, so that the sound shall appear to proceed from that spot. The words are pronounced by the organs usually employed for that purpose, but in such a manner as to give little or no motion to the lips, the organs chiefly concerned being those of the throat and tongue. The variety of sounds which the human voice is capable of thus producing, is altogether beyond common belief, and, indeed, is truly surprising. Adepts in this art will mimic the voices of all ages and conditions of human life, from the smallest infant to the tremulous voice of tottering age ; and from the intoxicated foreign beggar to the high bred, artificial tones of the fashionable lady. Some will also imitate the warbling of the nightingale, the loud tones of the whip-poor-will, and the scream of the peacock, with equal truth and facility. Nor are these arts confined to professed imitators; for in many villages boys may be found, who are in the habit of imitating the brawling and spitting of cats, in such a manner as to deceive almost every hearer.

The human voice is also capable of imitating almost every inanimate sound. Thus the turning and occasional creaking of a grindstone, with the rush of the water—the sawing of wood—the trundling and creaking of a wheel-barrow—the drawing of bottle corks, and the gurgling of the flowing liquor—the sound of air rushing through a crevice on a wintry night, and a great variety of other noises of the same kind, are imitated by the voice so exactly, as to deceive any hearer who does not know whence they proceed.

Upon what does the management of the voice depend ? 281. What is ventriloquism? Was this art known to the ancients? What is supposed, by some authors, concerning the responses at Delphi, Ephesus, &c.? Is ventriloquism a natural gift, or an acquired one?

ture; but many persons can, with a little practice, utter sounds and pronounce words without opening the lips or moving the muscles of the face; and this appears to be the great secret of the art.

SECTION XIII.

Pyronomics, or the Laws of Heat.

282. Pyronomics is the science which treats of the laws, the properties and operations of heat.

283. Whether heat is or is not a material substance, is not known; but it has been proved that the addition of heat to any substance produces no alteration in the weight of that substance. Hence it is inferred that heat has no weight.

284. Though heat passes through some bodies with more difficulty than through others, there is no body nor any kind of matter which can completely arrest its progress.

285. Heat is generally known by the name of Caloric. There are two kinds of heat; or rather, heat exists in two states, called free and latent. Free heat, or free caloric is that which is perceptible to the senses, as the heat of a fire, the heat of the sun, &c. Latent heat is that which exists in most kinds of substances, but is not perceptible to the senses, until it is brought out by mechanical or chemical action. Thus, when a piece of cold iron is hammered upon an anvil it becomes intensely heated; and when a small portion of sulphuric acid, or vitriol, is poured into a phial of cold water, the phial and the liquid immediately become hot.

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282. Of what does pyronomics treat? From what is it inferred that heat has no weight? 283. What is stated, in No. 283, with regard to heat? 284. Can the progress of heat be arrested? 285. What is caloric? In what two states does heat exist? What is free heat? Give some examples of free heat.

A further illustration of the existence of latent or concealed heat is given at the fireside every day. A portion of cold fuel is placed upon the grate or hearth, and a spark is applied to kindle the fire which warms us. It is evident that the heat given out by the fuel, when ignited, does not all proceed from the spark, nor can we perceive it in the fuel; it must, therefore, have existed somewhere in a latent state. It is, however, the effects of free heat, or free caloric, which are embraced in the science of pyronomics. The subject of latent heat belongs more properly to the science of chemistry.

286. The terms heat and cold, as they are generally used, are merely relative terms; for a substance which in one person would excite the sensation of heat, might, at the same time, seem cold to another.

Thus, also, to the same individual, the same thing may be made to appear, relatively, both warm and cold. If, for instance, a person were to hold one hand near to a warm fire, and the other on a cold stone, or marble slab, and then plunge both into a basin of lukewarm water, the liquid would appear cold to the warm hand and warm to the cold one.

287. The principal effects of heat, on bodies to which it is applied, are three; namely, *First*, heat dilates or increases the extension of all bodies, whether solid, liquid, or in the form of air, or gas. Thus, metals, wood and other substances, are expanded by the application of heat. *Secondly*, heat, when applied in sufficient quantity to many kinds of substances, transforms them from a solid to a fluid state. Thus, metals, glass and many other substances can be melted by the application of a sufficient degree of heat. *Thirdly*, heat, when applied in its greatest degree, destroys the texture of many kinds of substances by combustion. Thus, wood, coal, and other substances are burnt up by the application of heat.

288. The sources from which heat is derived are, *First*, from the sun, in connexion with light. *Secondly*, from mechanical operations, such as friction, percussion, compression, &c. *Thirdly*, from a variety of chemical operations, especially combustion; and *Fourthly*, from living animals and vegetables.

What is latent heat? Give some examples of latent heat? 286. How are the terms, heat and cold generally used? What illustration of this is given? 287. What are the three principal effects of heat on bodies to which it is applied? Give an example of each effect? 288. What are the sources from which heat is derived?

289. Heat tends to diffuse itself equally through all substances.

If a heated body be placed near a cold one, the temperature of the former will be lowered, while that of the latter will be raised.

290. All substances contain a certain quantity of heat; but, by its tendency to diffuse itself equally, and the difference in the power of different substances, to conduct it, bodies of the same absolute temperature appear to possess different degrees of heat.

Thus, if the hand be successively applied to a woollen garment, a mahogany table, and a marble slab, all of which have stood for some time in the same room, the woollen garment will appear the warmest, and the marble slab the coldest of the three articles; but if a thermometer be applied to each, no difference in the temperature will be observed.

From this it appears that some substances conduct heat readily, and others with great difficulty. The reason that the marble slab seems the coldest, is, that marble, being a good conductor of heat, receives the heat from the hand so readily that the loss is instantly felt by the hand; while the woollen garment, being a bad conductor of heat, receives the heat from the hand so slowly that the loss is imperceptible.

291. The different power of receiving and conducting heat, possessed by different substances, is the cause of the difference in the warmth of various substances used for clothing.

Thus, woollen garments are warm garments, because they part slowly with the heat which they acquire from the body, and, consequently, they do not readily convey the warmth of the body to the air; while, on the contrary, a linen garment is a cool one, because it parts with its heat readily, and as readily receives fresh heat from the body. It is, therefore, constantly receiving heat from the body and throwing it out into the air, while the woollen garment retains the heat which it receives, and thus encases the body with a warm covering.

For a similar reason ice, in summer, is wrapped in woollen cloths. It is then protected from the heat of the air, and will not melt.

292. Heat is received and conducted with the greatest readiness by metals.

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289. In what way does heat tend to diffuse itself? 290. Why do bodies of the same absolute temperature appear to possess different degrees of heat? What illustration of this is given? What appears from this? 291. What causes the difference in the warmth of substances used for clothing? Why are woollen garments warm? Why are linen ones cold? Why is ice wrapped in woollen in summer? 292. By what is heat received and conducted with the greatest readiness?

For this reason wooden spoons and forks are used in preference to silver ones, to take ice from a plate. The spoon is of the same temperature with all other articles in the room; and if it be of silver, or any other metal, it readily communicates its heat to the ice and melts it—but wooden spoons do not so readily part with their heat, and will not, therefore, melt the ice so readily.

For the same reason, the handles of tea and coffee pots are generally made of wood; parting with their heat less readily than metallic ones, they are less likely to be inconvenient to the hand, on account of their heat.

293. All bodies, whether solid, liquid, or in the form of gas, when violently compressed or extended, become warm.

Experiment. If a piece of Indian rubber be quickly stretched and applied to the lip, a sensible degree of heat will be felt. An iron bar, by being hammered, becomes red hot; and even water, when strongly compressed, gives out heat.

When air is forcibly compressed * by driving down the piston of a syringe, nearly closed at the end, great heat is produced. Syringes have been constructed on this principle for procuring fire, the heat, thus produced, being sufficient to kindle dry tinder.

294. All substances, with regard to their capacity for heat, may be divided into two classes, namely, combustible or inflammable bodies, and incombustible or non-inflammable bodies.

Vegetable Substances, charcoal, oils, most animal substances, as hair, wool, horn, fat, and all metallic bodies, are combustible.†

Stones, glass, salts, &c. are incombustible.

* The following fact is extracted from a newspaper, published in this city, December 3, 1836.

" *Solid Air.* The philosophers of Paris, by the aid of tremendously powerful apparatus, have succeeded in the consolidation of carbonic acid gas, one of the constituents of atmospheric air, so as to be both visible and tangible. The substance, at a late sitting of the French Academy, was distributed to the company, tasted and handled—and the sensation produced by its touch is described as 'the impression of extraordinary cold, which a solid gas produces, when returning from a state of air.' It is added, that the company were much surprised at the slight effect resulting to the organs of sensation from contact with a substance, the touch of which congeals mercury and spirits of wine, and causes the thermometer to descend to 90 degrees below zero."

† The word combustible literally means, that which can be burnt up. The pupil is referred to *Illust.* 3, page 12, for some remarks with regard to the consumption, or rather the alteration which takes place in bodies during combustion.

Why are wooden spoons and forks sometimes used in preference to silver ones? 293. What is stated in No. 293? What experiments are here related to illustrate this? What is said of the air when strongly compressed? What fact is related in the note? 294. Into what classes are all substances, with regard to their capacity for heat, divided? What substances are combustible? What substances are incombustible?

295. The pyrometer is an instrument to show the expansion of bodies on the application of heat. It consists of a metallic bar or wire, with an index connected with one extremity. On the application of the flame of a lamp, or heat from any other source, to any part of the bar, the bar expands and turns the index to show the degree of expansion.

296. The most obvious and direct effect of heat on a body, is to increase its extension in all directions.

Coopers, wheelwrights, and other artificers, avail themselves of this property in fixing iron hoops on casks, and the tires or irons on wheels. The hoop or tire having been heated, of course expands, and being adapted in that state to the cask or the wheel, as the metal contracts in cooling, it clasps the parts very firmly together.*

297. Heat not only expands metals, wood, &c. but also different kinds of stones, chalk, burnt brick, and especially glass.

These substances must, however, be freed from moisture; otherwise heat, by dissipating the moisture, will occasion contraction.

The effect of heat and cold,† in the expansion and contraction of glass, is an object of common observation; for it is this expansion and contraction which causes so many accidents with glass articles. Thus, when hot water is suddenly poured into a cold glass, of any

* From what has been stated above, it will be seen that an allowance should be made for the alteration of the dimensions in metallic beams or supporters, caused by the dilatation and contraction effected by the weather. In the iron arches of Southwark bridge, over the Thames, the variation of tho temperature of the air causes a difference of height, at different times, amounting to nearly an inch. A happy application of this principle to the mechanic arts, was made, some years ago, at Paris. The weight of the roof of a building, in the Conservatory of Arts and Trades, had pressed outwards the side walls of the structure, and endangered its security. The following method was adopted to restore the perpendicular direction of the structure. Several holes were made in the walls, opposite to each other, through which iron bars were introduced, which, stretching across the building, extended beyond the outside of the walls. These bars terminated in screws, at each end, to which large broad nuts were attached. Each alternate bar was then heated by means of powerful lamps, and their lengths being thus increased, the nuts on the outside of the building were screwed up close to it, and the bars were suffered to cool. The powerful contraction of the bars drew the walls of the building closer together, and the same process being repeated, on all the bars, the walls were gradually and steadily restored to their upright position.

† *Cold* is merely the absence of heat; or rather, more properly speaking, inferior degrees of heat are termed *cold.*

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295. What is a pyrometer? Of what does it consist? 296. What is the most obvious and direct effect of heat on a body? What follows from what has been stated above? What application of this principle is related in the note? 297. What other substances, beside metals, wood, &c. does heat expand? Why must the substances be freed from moisture? What is said of the effect of heat and cold on glass?

form, the glass, if it have any thickness, will crack; and, on the contrary, if cold water be poured into a heated glass vessel the same effect will be produced. The reason of which is this: heat makes its way but slowly through glass; the inner surface, therefore, when the hot water is poured into it, becomes heated, and, of course, distended before the outer surface, and the irregular expansion causes the vessel to break. There is less danger of fracture, therefore, when the glass is thin, because the heat readily penetrates it, and there is no irregular expansion.*

298. The expansion caused by heat in solid and liquid bodies differs in different substances; but aeriform fluids all expand alike, and undergo uniform degrees of expansion at various temperatures.

The expansion of solid bodies depends, in some degree, on the cohesion of their particles; but as gases and vapors are destitute of cohesion, heat operates on them without any opposing power.

299. The density of all substances is augmented by cold, and diminished by heat.

There is one remarkable exception to this remark, and that is in the case of water; which, instead of contracting, expands at the freezing point, or when it is frozen. This is the reason why pitchers, and other vessels, containing water and other similar fluids, are so often broken when the liquid freezes in them. For the same reason, ice floats † instead of sinking in water; for as its density is diminished, its specific gravity is consequently diminished.

* The glass chimneys, used for oil and gas burners, are often broken by being suddenly placed, when cold, over a hot flame. The danger of fracture may be prevented (it is said) by making a minute notch on the bottom of the tube, with a diamond. This precaution has been used in an establishment where six lamps were lighted every day, and not a single glass has been broken in nine years.

† Were it not for this remarkable property of water, large ponds and lakes, exposed to intense cold, would become solid masses of ice; for if the ice, when formed on the surface, were more dense (that is, more heavy) than the water below, it would sink to the bottom, and the water above, freezing in its turn, would also sink, until the whole body of the water would be frozen. The consequence would be the total destruction of all creatures, &c. in the water. But its lightness causes it to continue on the surface, protecting the water below from congelation.

When hot water is suddenly poured into a cold glass, why will the glass crack? When cold water is applied to a heated glass, why will the glass crack? 298. Is the expansion caused by heat in solid and liquid bodies the same in all substances? How do aeriform fluids differ, in this respect, from solid and liquid bodies? Upon what does the expansion of solid bodies, in some degree, depend? Why has heat more power over gases and vapors? 299. What effect has heat and cold upon the density of all substances? What exception is there to this remark? Why are the vessels, containing water, and other similar fluids, so often broken when the liquid freezes in them? Why does ice float upon the water instead of sinking in it? What is stated, in the note, with regard to this property of water?

300. Different bodies require different quantities of heat to raise them to the same temperature, and those which are heated with most difficulty retain their heat the longest.

Thus oil becomes heated more speedily than water, and it likewise cools more quickly.

301. When heat is thrown upon a bright or polished surface it is reflected,* and the angle of reflection will be equal to the angle of incidence. [*See note to No.* 274, *page* 100.]

302. When a certain degree of heat is applied to water it converts the water into steam or vapor. The temperature of steam is always the same with that of the liquid from which it is formed, while it remains in contact with that liquid. When closely confined its elastic power is sufficient to burst the vessel in which it is confined.

303. The elasticity or elastic force of steam is increased and diminished by heat and cold. The amount of pressure, therefore, which it will exert depends on the temperature at which it is formed. If the steam be formed from the water with great additions of heat, so as to increase its expansive power, it is called high pressure steam ; and this forms the distinction between high and low pressure steam engines. The great and peculiar property of steam, on which its mechanical agencies depend, is its power of creating, at one moment, a high degree of elastic force, and losing it instantaneously by the next moment.

* Advantage has been taken of this property of heat in the construction of a simple apparatus for baking. It is a bright tin case having a cover inclined towards the fire in such a manner as to reflect the heat downwards. In this manner use is made both of the direct heat of the fire, and the reflected heat, which would otherwise pass into the room. The whole apparatus, thus connected with the culinary department, is called, in New England, "The Connecticut baker."

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300. Can all bodies be raised to the same temperature by the same quantities of heat? What bodies retain their heat the longest? 301. What becomes of the heat which is thrown upon a bright or polished surface? How do the angles of incidence and reflection compare with each other? 302. When is water converted into steam or vapor? How does the temperature of the steam compare with that of the liquid from which it is formed, while it remains in contact with that liquid? 303. By what is the elasticity of steam increased and diminished? Upon what does the amount of pressure, which steam exerts, depend? When is it called high pressure steam? What is the great and peculiar property of steam, on which its mechanical agencies depend?

304. The steam engine is a machine moved by the expansive force of steam or vapor.

305. The steam or vapor of water occupies a space about 1700 times larger than water. If, therefore, the steam which fills the chamber of a cylinder be suddenly converted into water, it will occupy a much smaller space, and produce a vacuum in the cylinder.

306. The mode in which steam is made to act is by causing it to raise a solid piston, accurately fitted to the bore of a cylinder, like that in the forcing pump.

The piston rod rises by the impulse of expanding steam, admitted into the cylinder below. When the piston is thus raised, if the steam below it be suddenly condensed or withdrawn from under it, a vacuum will be formed, and the pressure of the atmosphere, on the piston above, will drive it down. The admission of more steam below it will raise it again, and thus a continued motion of the piston, up and down, will be produced. This motion of the piston is communicated to wheels, levers, and other machinery, in such a manner as to produce the effect intended.

This is the mode in which the engine of Newcomen and Savery, commonly called the atmospheric engine, was constructed.

The celebrated Mr. James Watt introduced two important improvements into the steam engine. Observing that the cooling of the cylinder by the water thrown into it to condense the steam, lessened the expansibility of the steam; after it had performed its office, he contrived a method to withdraw the steam from the principal cylinder, into a condensing chamber, where it is reconverted into water, and conveyed back to the boiler.

The other improvement consists in substituting the expansive power of steam for the atmospheric pressure. This was performed by admitting the steam into the cylinder *above* the raised piston, at the same moment that it is removed from *below* it; and thus the power of steam is exerted in the *descending* as well as in the ascending stroke of the piston; and a much greater impetus is given to the machinery than by the former method.

From the *double action* of the steam, *above*, as well as *below* the piston, and from the condensation of the steam, after it had performed its office, this engine is called Watt's *double acting condensing* steam engine.

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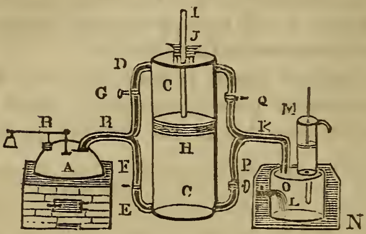
304. What is the steam engine? 305. How much larger space does steam occupy than water? 306. By what mode is steam made to act? By what impulse does the piston rise? What causes the piston to descend? What improvement did Mr. Watt introduce into the steam engine.

Illustration. Fig. 87 represents that portion of the steam engine in which steam is made to act, and propel such machinery as may be connected with it. The principal parts are the boiler, the cylinder and its piston, the condenser, the air pump, the steam pipe, the eduction pipe, and the cistern. In this figure A represents the boiler, C the cylinder, with H its piston. B, the steam pipe, with two *branches** communicating with the cylinder, the one above and the other below the piston. This pipe has two valves, F and G, which are opened and closed, alternately, by machinery connected with the piston. The steam is carried through this pipe by the valves, when open, to the cylinder both above and below the piston. K is the eduction pipe, having two branches, like the steam pipe, furnished with valves &c. which are opened and shut by the same machinery. By the eduction pipe the steam is led off from the cylinder as the piston ascends and descends.

Fig. 87.



L is the condenser, and O a stop cock for the admission of cold water. M is the air pump. N is the cistern of cold water in which the condenser is immersed. R is the safety valve. When the valves are all open the steam issues freely from the boiler, and circulates through all the parts of the machine, expelling the air.† Now, the valves F and Q, being closed, and G and P remaining open, the steam presses upon the cylinder and forces it down. As it descends it draws with it the end of the working beam, which is attached to the piston rod J, (but which is not represented in the figure.) To this working beam, (which is a lever of the first kind) bars or rods are attached, which, rising and falling with the beam and the piston, open the stop cock O, admitting a stream of cold water, which meets the steam from the cylinder and condenses it, leav-

* The steam and the eduction pipes are sometimes made in forms differing from those in the figure, and they differ much in different engines.

† This process is called blowing out, and is heard when a steamboat is about starting.

What does figure 87 represent? What are the principal parts? What does A represent? What does C represent? What does B represent? What does K represent? By what is the steam led off from the cylinder? What does L represent? What does O represent? What does M represent? What does N represent? What does R represent? When the valves are all open, what becomes of the steam? When the valves F and Q are closed, and G and P open, upon what does the steam press? What does the cylinder draw with it in its descent? Which of the mechanical powers is this working beam?

ing no force below the piston to oppose its descent. At this moment the rods attached to the working beam close the stop cocks, G and P, and open F and Q. The steam then flows in below the piston, and rushes from above it into the condenser, by which means the piston is forced up again with the same power as that with which it descended. Thus the steam cocks, G and P and F and Q, are alternately opened and closed; the steam passing from the boiler drives the piston alternately upwards and downwards, and thus produces a regular and continued motion. This motion of the piston being communicated to the working beam, is by that beam communicated to other machinery, and thus an engine of great power is obtained.

The air pump, M, the rod of which is connected with the working beam, carries the water from the condenser back into the boiler, by a communication represented in figure 88.

The safety valve R is made to open when the pressure of the steam, within the boiler, is too great. The steam then rushing through the aperture under the valve removes the danger of the bursting of the boiler.

307. The steam engine* is constructed in various forms; the principal of which are the high and the low pressure engines; or, as they are sometimes called, the non-condensing and the condensing engines.

The non-condensing or high pressure engines differ from the low pressure or condensing engines in having no condenser. The steam, after having moved the piston, is let off into the open air. As this kind of engine occupies less space, and is much less complicated, it is generally used on rail roads.

In the low pressure or condensing engines, the steam, after having moved the piston, is condensed or converted into water, and then conducted back into the boiler.

* The steam engine, as it is constructed at the present day, is the result of the inventions and discoveries of a number of distinguished individuals, at different periods. Among those who have contributed to its present state of perfection, and its application to practical purposes, may be mentioned the names of Somerset, the Marquis of Worcester, Savery, Newcomen, Fulton, and especially Mr. James Watt.

To the inventive genius of Watt the engine is indebted for the *condenser*, *the appendages for parallel motion*, the application of the *governor*, and for the *double action*. In the words of Mr. Jeffrey, it may be added that, "By his admirable contrivances, and those of Mr. Fulton, it has become a thing alike stupendous for its force and its flexibility--for the prodigious power it can exert, and the ease and precision, and ductility with which it can be varied, distributed, and applied. The trunk of an elephant, that can pick up a pin, or rend an oak, is as nothing to it. It can engrave a seal, and crush masses of obdurate metal before it—draw out, without breaking, a thread as fine as gossamer, and lift up a ship of war like a bauble in the air. It can embroider muslin and forge anchors—cut steel into ribands, and impel loaded vessels against the fury of the winds and waves.

What are attached to this working beam? What is their use? What becomes of the steam when the stop cocks G and P are closed and F and Q are open? How is the regular and continued motion produced? To what is this motion of the piston communicated? What is the use of the air pump M? For what is the safety valve R used? 307. What are the principal forms in which the steam engine is constructed? How do they differ from each other? What becomes of the steam after having moved the piston in the non-condensing engines? What kind of engines is generally used on rail roads? What becomes of the steam after having moved the piston in the condensing engines?

Fig. 88 represents Watt's double acting, condensing, steam engine, in which A represents the boiler, containing a large quantity of water, which is constantly replaced as fast as portions are converted into steam. B is the steam pipe, conveying the steam to the cylinder, having a steam cock *b* to admit or exclude the steam at pleasure.

C is the cylinder, surrounded by the jacket *c c*, a space kept constantly supplied with hot steam, in order to keep the cylinder from being cooled by the external air. D is the eduction pipe, communicating between the cylinder and the condenser. E is the condenser, with a valve *e* called the injection cock, admitting a jet of cold water, which meets the steam the instant that the steam enters the condenser. F is the air pump, which is a common suction pump, but is here called the air pump because it removes from the condenser not only the water, but also the air, and the steam that escapes condensation. G G is a cold water cistern, which surrounds the condenser and supplies it with cold water, being filled by the cold water pump which is represented by H. I is the hot well, containing water from the condenser. K is the hot water pump, which conveys back the water of condensation from the hot well to the boiler.

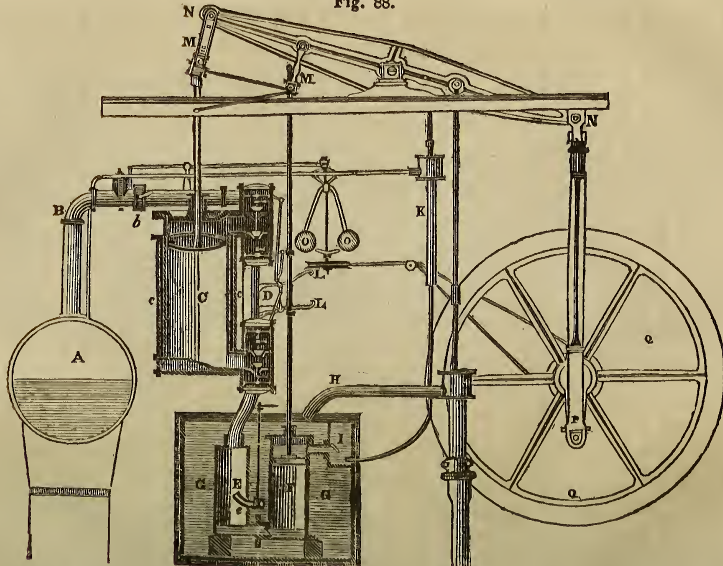
L L are levers, which open and shut the valves in the channel between the steam pipe, cylinder, eduction pipe, and condenser; which levers are raised or depressed by projections attached to the piston rod of the condenser. M M is an apparatus for changing the circular motion of the working beam into parallel motion, so that the piston rods are made to move in a straight line. N N is the working beam, which being moved by the rising and falling of the piston, attached to one end, communicates motion to the fly wheel by means of the crank P, and from the fly wheel the motion is communicated by bands, wheels or levers to the other parts of the machinery. O O is the governor. [*See fig.* 45, *No.* 193.]

The governor being connected with the fly wheel, is made to participate the common motion of the engine, and the balls will remain at a constant distance from the perpendicular shaft, so long as the motion of the engine is uniform; but whenever the engine moves faster than usual, the balls will recede farther from the shaft, and by raising a valve connected with the boiler, will let off such a portion of the force as to reduce the speed to the rate required.

The steam engine, thus constructed, is applied to boats to turn wheels having paddles attached to their circumference, which answer the purpose of oars. It is used, also, in workshops, factories, &c.; and different directions and velocities may be given to the motion produced by the action of the steam on the piston, by connecting the piston on the beam with wheels, axles, and levers, as represented in numbers 171 to 180, page 52.

What does fig. 88 represent? What does A represent? What does B represent? What does C represent? What does D represent? What does E represent? What does F represent? What does G G represent? What does J represent? What does K represent? What does L L represent? What does M M represent? What does N N represent? What does O O represent? What is said of the governor?

Fig. 88.



WATT'S DOUBLE ACTING CONDENSING STEAM ENGINE.

308. The Locomotive Engine is a high pressure steam engine, mounted on wheels, and used to draw loads on a rail road, or other level roads. It is usually accompanied by a large wagon, called a *tender*, in which the wood and water, used by the engine, are carried.

Fig. 89 represents a side view of the internal construction of a locomotive steam engine; in which, F represents the fire box, or place where the fire is kept; D the door through which the fuel is introduced. G one of the bars of the grate at the bottom. The spaces marked B are the interior of the boiler, in which the water stands at the height indicated by the dotted line. The boiler is closed on all sides; all its openings being guarded by valves. The tubes marked *e e* conduct the smoke and flame of the fuel through the boiler to the chimney C C, serving, at the same time, to communicate the heat to the remotest part of the boiler. By this arrangement none of the heat is lost, as these tubes are all surrounded by the water. S S S is the steam pipe, open at the top B S, having a steam-tight cock or regulator V, which is opened and shut by the crank H, extending outside of the boiler, and which is managed by the engineer.*

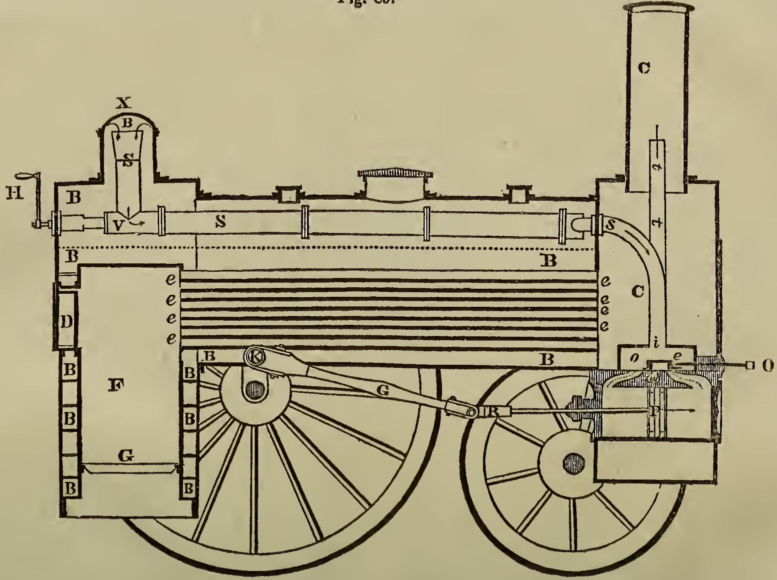
The operation of the machine is as follows: the steam being generated in great abundance in the boiler, and being unable to escape out of it, acquires a considerable degree of elastic force. If at that moment the cock V is opened, by the handle H, the steam penetrating into the tube S at the top near X, and in the direction of the arrows, passes through the tube and the valve V, and enters the valve box *i*. There, a sliding valve *o o*, which moves at the same time with the machine, opens for the steam a communication successively with each end of the cylinder. Thus, in the figure, the entrance on the left hand of the sliding valve is represented as being open, and the steam follows in the direction of the dotted line into the cylinder, where its expansive force will move the piston in the direction of the arrow. The steam or air on the other side of the piston passes out in the direction of the dotted line to *u*, which communicates with the tube *t t*, from which it passes into the chimney C, and thence into the open air. The sliding valve *o o* now moves and leaves the right hand aperture open, while it closes the one on the left. The steam then draws the piston back, and that portion of the steam on the left of the piston, having performed its office, passes out of the aperture *u*, an opening to which is made by the new position of the sliding valve. Thus, the sliding valve opening a communication, alternately, with each side of the piston, the steam is admitted on both sides of the piston, and having performed its office, it passes through the aperture *u* to the tube *t t* and the chimney C, and from thence into the open air.

Motion being thus given to the piston, it is communicated, by

* This cock is not seen in the figure because it is in the *inside* of the tube. The figure represents the outside.

Describe the *locomotive* steam engine. In the 89th figure what do F D and G represent? What do the following references respectively represent, namely, S S S? B B B? *e e e e*? C C? *o o*? *u*? H? *t t*? P? R G K?

Fig. 89.



VIEW OF THE INTERNAL CONSTRUCTION OF THE LOCOMOTIVE STEAM ENGINE.

means of the rod R and the beam G, to the crank K; which, being connected with the axle of the wheel, causes it to turn, and thus moves the machine.

Thus constructed, and placed on a railroad, the locomotive steam engine is advantageously used as a substitute for horse power, for drawing heavy loads.

The apparatus of safety valves and other appliances, for the management of the power produced by the machine, are the same in principle, though different in form from those used in other steam engines; for a particular description of which, the student is referred to practical treatises upon the subject.*

309. Heat is propagated in two ways, namely, by conduction and by radiation. Heat is propagated by conduction when it passes from one substance to another in contact with it. Heat is propagated by radiation when it passes through the air or any other elastic fluid. Different bodies conduct heat with different degrees of facility. The metals are the best conductors, and among metals silver is the best conductor.

For this reason any liquid may be heated in a silver vessel more readily than in any other of the same thickness. The metals stand in the following order, with respect to their conducting power, namely, silver, gold, tin, copper, platina, steel, iron and lead.

It is on account of the conducting power of metals† that the handles of metal tea pots, and coffee pots, are commonly made of wood; since, if they were made of metal, they would become too hot to be grasped by the hand, soon after the vessel is filled with heated fluid. Wood conducts heat very imperfectly. It may be held by the fingers very near the part which is burning, or red hot. Animal and vegetable substances, of a loose texture, such as fur, wool, cotton, &c. conduct heat very imperfectly; hence their efficacy in preserving the warmth of the body.

310. Heat is reflected from bright surfaces; while black or dark colored bodies absorb the heat that falls on them.

* In "*A Practical Treatise on Locomotive Engines upon Railways*," by the *Chevalier F. M. G. DePambour*, the reader will find a particular description of all the parts of the locomotive engine.

† Metals, on account of their conducting power, cannot be handled when raised to a temperature above 120 degrees of Fahrenheit. Water becomes scalding hot at 150 deg., but air, heated far beyond the temperature of boiling water, may be applied to the skin without much pain. Sir Joseph Banks, with several other

309. In what two ways is heat propagated? When is it propagated by conduction? When is it propagated by radiation? Do all bodies conduct heat with the same degree of facility? What bodies are the best conductors? In what order do the metals stand with respect to their conducting power? Is wood a good conductor of heat? Why are wool, fur, &c. so efficacious in preserving the warmth of the body? What is related, in the note, with regard to the conducting power of heat? 310. What bodies reflect the heat? What bodies absorb the heat?

This is the reason why the bright brass andirons, or any other bright substances, placed near a hot fire, seldom become heated; while other dark substances, further removed from the fire, become too hot for the hand.

Snow or ice will melt under a piece of black cloth, when it will remain perfectly solid under a white one. The farmers, in some of the mountainous parts of Europe, are accustomed to spread black earth, or soot, over the snow, in the spring, to hasten its melting, and enable them to commence ploughing early.

SECTION XIV.

Optics.

311. Optics is the science that treats of light, colors and vision, or sight.

312. The science of optics divides all substances into the following classes; namely, luminous, transparent, and translucent; reflecting, refracting and opaque.

313. Luminous bodies are those which shine by their own light; that is, by light proceeding from their own substance; such as the sun, the stars, a burning lamp, or a fire.

314. Transparent substances are those which allow light to pass through them freely, so that objects can be distinctly seen through them; as glass, water, air, &c.

315. Translucent bodies are those which permit a portion of light to pass through them; but render the object behind them indistinct; as horn, oiled paper, colored glass, &c.

gentlemen, remained some time in a room when the heat was 52 degrees above the boiling point—but, though they could bear the contact of the heated *air*, they could not touch any metallic substance, as their watch chains, money, &c. Eggs, placed on a tin frame, were roasted hard in twenty minutes; and a beef steak was overdone in thirty three minutes.

Chantrey, the celebrated sculptor, has an oven which he uses for drying his plaster cuts and moulds. The thermometer generally stands at 300 deg. in it, yet the workmen enter, and remain in it some minutes, without difficulty; but a gentleman once entering it with a pair of silver-mounted spectacles on, had his face burnt when the metal came in contact with the skin.

Why do bright bodies, when placed near a hot fire, seldom become heated? 311. Of what does optics treat? 312. Into what classes does the science of optics divide all substances? 313. What are luminous bodies? Give an example of a luminous body? 314. What are transparent bodies? Give an example of a transparent body. 315 What are translucent bodies? Give an example of a translucent body.

316. Reflecting substances are those which do not permit light to pass through them; but throw it off in a direction more or less oblique, according as it falls on the reflecting surface; as polished steel, looking glasses, polished metal, &c.

317. Refracting substances are those which turn the light from its course, in its passage through them; and opaque substances are those which permit no light to pass through them; as metals, wood, &c.

318. It is not known what light is. Sir Isaac Newton supposed it to consist of exceedingly small particles, moving from luminous bodies; others think that it consists of the undulations of an elastic medium, which fills all space, and which produces the sensation of light to the eye, in the same manner as the vibrations of the air produce the sensation of sound to the ear.

Which of these opinions is the more correct, it is not possible, nor is it important, to decide. The laws relating to light, and all the phenomena, which are explained in the science of optics, are equally consistent with either opinion.

319. A ray of light is a single line of light proceeding from a luminous body.

320. Rays of light are said to diverge when they separate more widely, as they proceed from the luminous body.

Fig. 90.

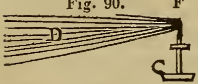


Fig 90 represents the rays of light diverging as they proceed from the luminous body, from F to D.

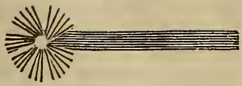
321. Rays of light are called converging when they approach each other. The point at which converging rays meet is called the focus.

Fig. 91.

Fig. 91 represents converging rays of light, and the point F is the focus.

316. What are reflecting substances? Give an example of a reflecting body? 317. What are refracting substances? What are opaque substances? 318. What is light? What did Sir Isaac Newton suppose it to be? What other opinions have been formed concerning it? 319. What is a ray of light? What is a beam of light? 320. When are rays of light said to diverge? What does fig. 90 represent? 321. When are rays of light called converging? What is the point, at which converging rays meet, called?

Fig. 92.



322. A beam of light consists of many rays running in parallel lines. Fig. 92 represents a beam of light. A pencil of light is a collection of diverging or converging rays.

323. A medium is any substance, solid or fluid, through which light can pass; as water, glass, air, &c.

324. The rays of light which proceed from terrestrial bodies, proceed in a diverging manner, until they meet with some refracting substance; but the rays of the sun diverge so little, on account of the immense distance of that luminary, that they are considered parallel.

325. Light, when proceeding from the sun, or any other luminous body, is projected forward in straight lines in every possible direction. It moves with a rapidity but little short of 200,000 miles in a second of time.

326. Every point of a luminous body is a centre, from which light radiates in every direction. Rays, proceeding from different bodies, cross each other without interfering.

327. Light is governed by the laws of motion, but is not influenced by those of gravity; or, in other words, it has no weight. Thus, when it falls upon any surface, the same law applies to it as that which governs all bodies, (*and this may be considered as one of the fundamental laws of optics, as well as of mechanics,*) namely, that the angle of incidence is always equal to the angle of refraction. [*See No.* 121, *page* 32.]

328. A shadow is the darkness produced by the intervention of an opaque body, which prevents the rays of light from reaching an object behind the opaque body.

Shadows are of different degrees of darkness, because the light

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322. What does fig. 92 represent? What is a pencil of light? 323. What is a medium? 324. In what manner do the rays of light proceed from terrestrial bodies? In what kind of lines do the rays of light proceed from the sun? 325. In what way is light projected forward from any luminous body? With what rapidity does it move? 326. From what point, in a luminous body, does light radiate? 327. By what laws is light governed? Has it any weight? What is one of the fundamental laws of optics? 328. How is a shadow produced?

from other luminous bodies reaches the spot where the shadow is formed. Thus, if a shadow is formed when two candles are burning in a room, that shadow will be both deeper and darker if one of the candles be extinguished. The darkness of a shadow is proportioned to the intensity of the light, when the shadow is produced by the interruption of the rays from a single luminous body.*

329. When a luminous body is larger than an opaque body, the shadow of the opaque body will gradually diminish in size till it terminates in a point. The form of the shadow will be that of a cone.

Fig. 93.

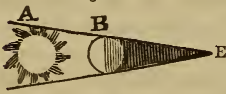

Illustration. Fig. 93. A represents the sun, and B the moon. The sun, being much larger than the moon, causes it to cast a converging shadow, which terminates at E.

330. When a luminous body is smaller than the opaque body, the shadow of the opaque body gradually increases in size, with the distance, without limit.

Fig. 94.

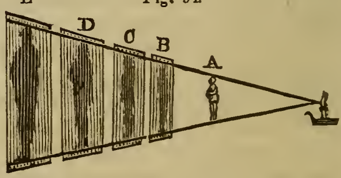

Illustration. In fig. 94 the shadow of the object, A, increases in size at the different distances, B, C, D, E, or, in other words, it constantly diverges.

In estimating the effect of shadows, we must consider the apparent not the real dimensions of the luminous body. The sun *appears* smaller than the generality of the terrestrial objects which it illumines; all objects, therefore, which are apparently larger than the sun will cast a diverging or enlarged shadow.

* As the degree of light and darkness can be estimated only by comparison, the strongest light will appear to produce the deepest shadow. Hence, a total eclipse of the sun occasions a more sensible darkness than midnight, because it is immediately contrasted with the strong light of day.

Why are shadows of different degrees of darkness? To what is the darkness of a shadow proportioned, when the shadow is produced by the interruption of the rays from a single luminous body? 329. What is said of the shadow of the opaque body, when the luminous body is the larger? Explain fig. 93. 330. What is said of the shadow of the opaque body, when the luminous body is the smaller? Explain fig. 94. What dimensions of the luminous body must we consider in estimating the effect of shadows? Why do objects which are illumined by the sun, and which are really smaller than the sun, cast a diverging or enlarged shadow?

331. When several luminous bodies shine upon the same object, each one will produce a shadow.

Fig. 95.

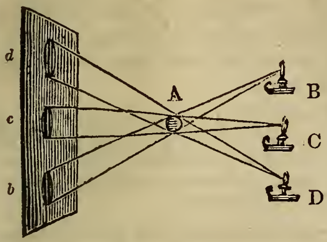

Fig. 95 represents a ball A illuminated by the three candles, B C and D. The light B produces the shadow *b*, the light C, the shadow *c*, and the light D, the shadow *d*; but as the light from each of the candles shines upon all the shadows, except its own, the shadows will be faint.

332. When rays of light fall upon an opaque body, which they cannot pass, part of them are absorbed, and part are reflected, and rebound back, like an elastic ball which is thrown against a wall. By the reflection of light is meant its return or passage from a reflecting substance.

In this respect, light is governed by the same laws as those which relate to solid elastic bodies.

333. When light falls perpendicularly on an opaque body, it is reflected back in the same line, towards the point whence it proceeded. If it fall obliquely, it will be reflected obliquely in the opposite direction; and in all cases the angle of incidence * will be equal to the angle of reflection. This is the fundamental law of reflected light. [*See No.* 337.]

334. Opaque objects are seen only by reflected light. Luminous bodies are seen by the rays of light which they send directly to our eyes.

* The angles of incidence and reflection have already been explained in page 32, No. 121. As the law of reflected light is one of the most important in the science of optics, it is necessary that the pupil have a clear idea of it. He must, therefore, view the particles of light as so many minute balls, bounding against a surface, and reflected according to this law.

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331. How many shadows are produced when several luminous bodies shine upon the same object? Explain fig. 95. 332. What is the consequence when rays of light fall upon an opaque body which they cannot pass? What is meant by the reflection of light? By what laws is light governed, in this respect? 333. How is light reflected when it falls perpendicularly on an opaque body? How is it reflected when it falls obliquely? How do the angles of incidence and reflection compare with each other? How should every particle of light be viewed in order to have a clear idea of it? 334. By what light are opaque objects seen? How are luminous bodies seen?

335. The intensity of light is diminished every time it is reflected, because all bodies have a tendency to absorb a portion of the light which they receive.

336. Every portion of a reflecting surface reflects an entire image of the luminous body shining upon it; but no individual can see more than one image from the same surface at the same time.

When the sun or the moon shines upon a sheet of water, every portion of the surface reflects an entire image of the luminary; but as the image can be seen only by reflected rays, and the angle of reflection is always equal to the angle of reflection, the image can be seen only in that spot where these angles meet.

337. Objects seen by moonlight appear fainter than when seen by daylight, because the light by which they are seen has been twice reflected.

The moon is not a luminous body, but its light is caused by the sun shining upon it. This light, reflected from the moon and falling upon any object is again reflected by that object. It suffers, therefore, two reflections; and since (*See No.* 335.) a portion is absorbed by each surface that reflects it, the light must be proportionally fainter. In traversing the atmosphere, also, the rays, both of the sun and moon, suffer diminution; for, though the pure air is a transparent medium, which transmits the rays of light freely, it is generally loaded with vapors and exhalations, by which some portion of them is absorbed.

338. All objects are seen by means of the rays of light emanating or reflected from them; and when no light falls upon a body it becomes invisible.

This is the reason why none but luminous bodies can be seen in the dark. For the same reason, objects in the shade, or in a darkened room appear indistinct, while those which are exposed to a strong light can be clearly seen.

339. When rays of light, proceeding from any object, enter a small aperture, they cross one another and form an inverted image of the object.

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335. Why is the intensity of light diminished every time it is reflected? 336. Does every portion of a reflecting surface reflect an entire image of the luminous body shining upon it? How many images can be seen? When the sun or moon shines upon a sheet of water, why do we not see an image reflected from every portion of the surface? 337. Why do objects, seen by moonlight, appear fainter than when seen by daylight? By what light does the moon shine? What absorbs some of the rays of light in traversing the atmosphere? 338. How are all objects seen? Why can none but luminous bodies be seen in the dark? 339. What kind of an image is formed when rays of light, proceeding from an object, enter a small aperture?

Fig. 96.

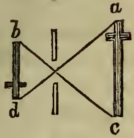


Illustration. Fig. 96 represents the rays from an object *a c* entering an aperture. The ray from *a* passes down through the aperture to *d*, and the ray from *c* passes up to *b*, and thus these rays, crossing at the aperture, form an inverted image on the wall. The room in which this experiment is made should be darkened, and no light permitted to enter, excepting through the aperture. It then becomes a camera obscura.*

340. The angle of vision is the angle formed at the eye by two lines drawn from opposite parts of an object.

Fig. 97.

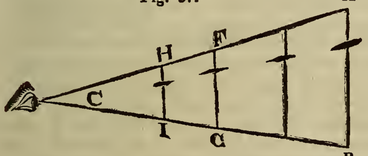
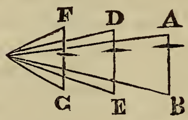


Fig. 97 represents the angle of vision. The line A C proceeding from an extremity of the object meets the line B C proceeding from the opposite extremity, and forms an angle at the eye, or C; and this is the angle of vision.

Fig. 98 represents the different angles, made by the same object, at different distances. From an inspection of the figure, it is evident that the nearer an object is to the eye, the wider must be the opening of the lines to admit the extremities of the object; and, consequently, the larger the angle under which it is seen; and, on the contrary, that objects at a distance will form small angles of vision. Thus, in this figure, the three crosses, F G, D E, and A B are all of the same size; but A B, being the most distant, subtends the smallest angle † A C B, while

Fig. 98.



* These words signify *a darkened chamber.* In the future description which will be given of *the eye*, it will be seen that the camera obscura is constructed on the same principle as the eye. If a convex lens, (*See No.* 357,) be placed in the aperture, an inverted picture, not only of a single object, but of the entire landscape, will be formed on the wall. A portable camera obscura is made by admitting the light, into a box of any size, through a convex lens, which throws the image upon an inclined mirror, from whence it is reflected upwards to a plate of ground glass. In this manner a beautiful but diminished image of the landscape, or of any group of objects, is presented on the plate in an erect position.

† The apparent size of an object depends upon the size of the angle of vision. But we are accustomed to correct, by experience, the fallacy of appearances; and, therefore, since we know that real objects do not vary in size, but that the angles under which we see them do vary with the distance, we are not deceived by the

Illustrate this by fig. 96. What is a camera obscura? How can a portable camera obscura be made? 340. How is the angle of vision formed? Explain fig. 97. What does fig. 98 represent? What effect has the nearness of the object to the eye, on the angle? Illustrate this by the figure.

D E and F G, being nearer to the eye, situated at C, form respectively the larger angles, D C E and F C G.

341. When an object, at any distance, does not subtend an angle of more than two seconds of a degree, it is invisible.

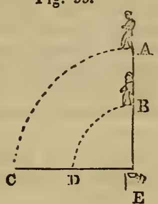
At the distance of four miles a man of common stature will thus become invisible.

342. When the velocity of a moving body does not exceed twenty degrees in an hour, its motion is imperceptible.

It is for this reason that the motion of the heavenly bodies is invisible, notwithstanding their immense velocity.

Illustration. The real velocity of a body in motion round a point, depends on the space comprehended in a degree. The more distant the moving body from the centre, or, in other words, the larger the circle which it has to describe, the larger will be the degree. In fig. 99 if the man at A, and the man at B both start together, it is manifest that A must move more rapidly than B, to arrive at C at the same time that B reaches D; because the arc A C is the arc of a larger circle than the arc B D. But to the eye at E, the velocity of both appears to be the same, because both are seen under the same angle of vision.

Fig. 99.



343. Light is said to be reflected when it is thrown off from the body on which it falls.

It has already been stated (*See No.* 332) that when light falls upon any body, part of it is absorbed and part is reflected. It remains now to be observed that light is reflected in the largest quantities from the most highly polished surfaces. Thus, although most substances reflect it in a degree, polished metals, looking-glasses, or

variations in the appearance of objects. Thus, a house, at a distance, appears absolutely smaller than the window through which we look at it; otherwise we could not see it through the window; but our knowledge of the real size of the house prevents our alluding to its apparent magnitude. In fig. 98 it will be seen that the several crosses, A B, D E, F G and H I, although very different in size, on account of their different distances, subtend the same angle A C B; they, therefore, all appear to the eye to be of the same size.

It is upon a correct observance of the angle of vision that the art of perspective drawing is indebted for its accuracy.

Upon what does the apparent size of an object depend? Why do objects appear so large? To what is the art of perspective drawing indebted for its accuracy?
341. How large an angle must a body subtend to be visible? 342. When is the motion of a body invisible? Why is the motion of the heavenly bodies invisible? Upon what does the real velocity of a body, in motion round a point, depend? Explain fig. 99. Why does the velocity of both, to an eye at E, appear to be the same? 343. When is light said to be reflected? What becomes of the light which falls upon bodies? What surfaces reflect the largest quantity of light?

mirrors, &c. reflect it in so perfect a manner as to convey to our eyes, when situated in a proper position to receive them, perfect images of whatever objects shine on them, either by their own, or by borrowed light.

344. That part of the science of optics which relates to reflected light is called Catoptrics.

345. Rays of light are reflected according to the same laws which regulate the motions of elastic solid bodies. Thus, a ray falling on a reflecting surface will be thrown off from that surface in such a manner that the angle of incidence will be equal to the angle of reflection.* This is the fundamental law of catoptrics or reflected light.

346. An incident ray is a ray proceeding *to*, or falling *on* any surface; and a reflected ray is the ray which proceeds *from* any reflecting surface.

Fig. 100.

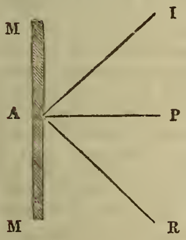


Fig. 100 is designed to show the angles of incidence and of reflection. In this figure, M A M is a mirror, or reflecting surface. P is a line perpendicular to the surface. I A represents an incident ray, falling on the mirror in such a manner as to form, with the perpendicular P, the angle I A P. This is called the angle of incidence. The line R A is to be drawn on the other side of P A in such a manner as to have the same inclination with P A as I A has, so that the angle R A P will be equal to I A P. The line R A will then show the course of the reflected ray; and the angle R A P will be the angle of reflection.

From whatever surface a ray of light is reflected, whether it be a plain surface, a convex surface, or a concave surface, this law invariably prevails; so that if we notice the inclination of any incident ray, and the situation of the perpendicular to the surface, on which it falls, we can always determine in what manner, or to what point it will be reflected. This law explains the reason why, when

* The angles of incidence and reflection have already been described in page 33, No. 121, but as all the phenomena of reflected light depend upon the law stated above, and a clear idea of these angles is necessary, in order to understand the law, it is deemed expedient to repeat in this connexion the explanation already given.

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344. What is catoptrics? 345. By what laws are rays of light reflected? What is the fundamental law of catoptrics? 346. What is an incident ray? What is a reflected ray? What does fig. 100 represent? Explain the fig. Do the different kinds of surfaces, from which light is reflected, cause any variation from this rule?

we are standing on one side of a mirror, we can see the reflection of objects on the opposite side of the room, but not those on the same side on which we are standing. It explains, also, all the apparent peculiarities of the reflection of the different kinds of mirrors.

347. There are three kinds of mirrors used in optics, namely, the plain, the concave, and the convex mirror. Plain mirrors are those which have a flat surface, such as a common looking-glass; and they neither magnify nor diminish the image of objects reflected from them.

348. Convex mirrors have a convex surface, that is, a surface bulging outwards; and they diminish the image of objects reflected from them. A convex mirror is a portion of the outside of a sphere.

349. Concave mirrors have a concave surface, that is, a surface hollowing inwards; and under certain circumstances magnify the image of objects which they reflect. A concave mirror is a portion of the inner surface of a sphere.

Fig. 101.

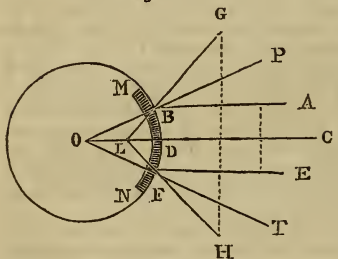


Illustration. In fig. 101 M N represents both a convex and a concave mirror. They are both a portion of a sphere of which O is the centre. The outer part of M N is a convex, and the inner part is a concave mirror. Let G B and H F be two incident rays falling on the surface of the convex mirror, M N, and the lines P B and T F represent the perpendiculars* at the points where the incident rays strike the reflecting surface; G B P and H F T will be the angles of incidence; and as the angles of reflection must be

* It is evident that the dotted lines, P B and T F are perpendicular to the circle, and, of course, to the arc M N, because when prolonged they will meet at the centre O.

How can you explain the reason, why, when standing on one side of a mirror, we see the reflected objects on the opposite side? 347. What are plain mirrors? How do they make the image appear? 348. What are convex mirrors? How do they make the image appear? What part of a sphere is a convex mirror? 349. What are concave mirrors? How do they make the image appear? What part of a sphere is a concave mirror? In fig. 101, which part of the sphere represents a convex mirror? Which part a concave mirror? Explain the fig.

equal to them, and on the other side of the perpendiculars, it is evident that the incident rays will be reflected in the lines B A and F E, that is, that the angles of reflection, P B A and T F E will be equal to the angles of incidence. Now, if the rays G B and H F proceed from the extremities of an object, it is evident that the dotted line G H will be the length of the object; but the length of the image is represented by the dotted line A E which is much shorter than G H; from which it is evident that the convex mirror reflects a diminished image of an object.

In a similar manner, it may be shown that concave mirrors, under certain circumstances, present magnified* images of objects reflected by them.

Concave mirrors have the peculiar property of forming images in the air. The mirror and the object being concealed behind a screen or a wall, and the object being strongly illuminated, the rays from the object fall upon the mirror, and are reflected by it through an opening in the screen or wall, forming an image in the air. Showmen have availed themselves of this property of concave mirrors, in producing the appearance of apparitions, which have terrified the young and the ignorant. These images have been presented with great distinctness and beauty, by raising a fine transparent cloud of blue smoke, by means of a chafing-dish, around the focus of a large concave mirror.

The true focus of a concave mirror is a point equally distant from the centre and the surface of the sphere, of which the mirror is a portion.

350. When an object is further from a concave mirror than its focus, the image will be inverted; but when the object is between the mirror and its focus, the image will be upright, and grow larger in proportion as the object is placed nearer to the mirror.

* A concave mirror will present a magnified, a diminished, or an equal image, according as the object is placed, nearer or more remote from the surface of the mirror?

The reason why convex mirrors diminish, and concave mirrors, under certain circumstances, magnify the images of objects, may be more clearly understood by the following explanation:

According to the principle stated in No. 340, page 125, the apparent size of all objects depends upon the *angle of vision*, or the angle under which they are seen. According, also, to the principle stated in No. 345, page 127, the angle of incidence must be equal to the angle of reflection. [*These two principles must be clearly understood, as the whole explanation depends upon them.*]

Do concave mirrors always present magnified images? What peculiar property belongs to concave mirrors? How can this be done? Where is the true focus of a concave mirror? 350. How does an object appear when placed farther from a concave mirror than its focus? How must an object be placed to appear upright? In what proportion does the rise of the object increase?

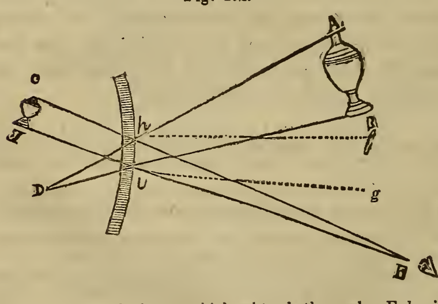
351. The following facts result from the operation of the law already stated as the fundamental law of catoptrics; namely, that the angles of incidence and reflection are always equal. The truth of these statements may be illustrated by simple drawings; always recollecting, in drawing the figures, to make the angles of incidence and reflection equal. The whole may also be shown by the simple experiment of placing the flame of a candle in various positions, before both convex and concave mirrors:

First. With regard to Convex Mirrors.

1. Parallel rays, reflected from a CONVEX surface, are made to diverge.
2. Diverging rays, reflected from a CONVEX surface, are made more diverging.
3. When converging rays tend towards the focus of parallel rays they will become parallel when reflected from a CONVEX surface.
4. When converging rays tend to a point nearer the surface than the focus, they will converge less when reflected from a CONVEX surface.

Now, in Fig. 102, which represents an object reflected by a *convex* mirror, the ray A *h*, passing from the upper extremity of the vase A B, must be reflected in such a manner as to make the angle of incidence A *h f* equal to the angle of reflection *f h* E; and, in like manner, the ray B *i*, proceeding from the lower extremity, must be reflected in such a manner as to make the angle B *i* g and *g i* E equal; the dotted lines, *f h* and g *i*, in both cases representing the perpendiculars to the reflecting surface. Now, by continuing the lines *a h* and B *i* until they meet in D, it will be seen that the angle of vision *h* E *i*, or what is the same thing, the angle *c* E *d* is less than the angle A D B; therefore, the image which subtends the angle *c* E *d* will appear less than the object which subtends the angle A D B. Hence, it appears that concave mirrors diminish the apparent size of an object.

Fig. 102.



In a similar manner, it may be proved, that a concave mirror presents a magnified image, when the object is nearer to the surface of the mirror than its principal focus.

In Fig. 103 the ray *a h*, proceeding from the upper extremity of the vase *a* B,

351. What facts are stated with regard to convex mirrors, as resulting from the fundamental law of catoptrics? 1. What is said of parallel rays? 2. What is said of diverging rays? 3. What is said of converging rays, when they tend towards the focus of parallel rays? 4. What is said of converging rays, when they tend to a point nearer the surface than the focus?

5. If converging rays tend to a point between the focus and the centre, they will diverge as from a point on the other side of the centre, farther from it than the point towards which they converged.

6. If converging rays tend to a point beyond the centre, they will diverge as from a point on the contrary side of the centre, nearer to it than the points towards which they converged.

7. If converging rays tend to the centre when reflected from a CONVEX mirror, they will proceed in a direction as far from the centre.

Secondly. With regard to Concave Mirrors.

8. Parallel rays, reflected from a CONCAVE surface, are made converging.

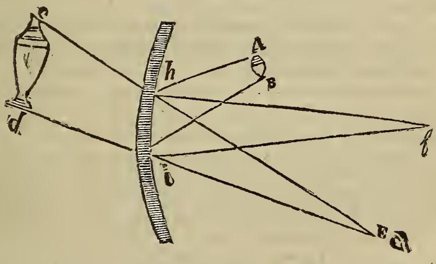
9. Converging rays, falling upon a CONCAVE surface are made to converge more.

10. Diverging rays, falling upon a CONCAVE surface, if they diverge from a focus of parallel rays, become parallel.

11. If from a point nearer to the surface than that focus, they diverge less than before reflection.

falling on the reflecting surface so as to form the angle of incidence A *h f*, will be reflected so as to form the angle *f h* E; and the ray B *i*, proceeding from the lower extremity, will be reflected in such a manner that the angle B *i f* shall be equal to *f i* E. It will thus be seen that the angle of vision *h* E *i* will be greater than the angle of vision which would be formed by the object A B when placed at a similar distance from the eye at E; or, in other words, that the distance from *h* to *i* is greater than the distance from A to B; and the image will occupy the space *h i* in the mirror, and will, consequently, appear as much larger than the object, as *h i* exceeds A B.

Fig. 103.



In the explanation of figures 102 and 103, it is to be observed, that no reflected rays from the objects A B can be seen by the eye at E, except those which proceed in such a manner as to make an angle, formed by lines proceeding first from the object to the reflecting surface, and then from the reflecting surface to the eye, wherever it may be situated. It will be seen by an inspection of the figures, that

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5. What is said of converging rays, when they tend to a point between the focus and the centre? 6. What is said of converging rays, when they tend to a point beyond the centre? 7. What is said of converging rays, when they tend to the centre? 8. What is said with regard to parallel rays, when reflected from a concave surface? 9. What is said of converging rays? 10. What is said of diverging rays, if they diverge from a focus of parallel rays? 11. What, if from a point nearer to the surface than that focus?

12. If from a point between that focus and the centre, they converge after reflection to some point, on the contrary side of the centre, and farther from the centre than the point from which they diverged.

13. If from a point beyond the centre, the reflected rays will converge to a point on the contrary side, but nearer to it than the point from which they diverged.

14. If from the centre, they will be reflected thither again.

The above fourteen principles, relating to rays of light reflected from convex and concave surfaces, all result from the same fundamental laws of catoptrics, which has already been stated several times; namely, that when light falls on *any* reflecting surface it will invariably be reflected in such a manner as to make the angles of reflection equal to the angle of incidence.

the rays will proceed precisely as is indicated by the figures, *and in no other way.* The reason why concave mirrors do not *always* magnify the image, will appear from the consideration that the angle of vision, under which the image is seen, depends upon the manner in which the incident rays fall upon the reflecting surface, and that, consequently, if the rays proceed from a point *beyond*, or even *at* the principal focus, that they will form a different angle at the surface, and that, consequently, the angle of reflection will be different. As the angle of vision depends upon these angles, it must vary as they vary ; and it can be shown, that if the object be placed beyond the principal focus, that the angle of vision, being altered, it will cause the image to appear differently.

There are three cases to be considered with regard to the effects of concave mirrors:

1. When the object is placed between the mirror and the principal focus.

2. When it is situated between its centre of concavity and that focus.

3. When it is more remote than the centre of concavity.

1. In the first case, the rays of light diverging after reflection, but in a less degree than before such reflection took place, the image will be larger than the object, and appear at a greater or smaller distance from the surface of the mirror, and behind it. The image in this case will be erect.

2. When the object is between the principal focus and the centre of the mirror, the apparent image will be behind the object, appearing very distant when the object is at or just beyond the focus, and advancing towards it as it recedes towards the centre of concavity, where, as already stated, the image and the object will coincide. During this retreat of the object, the image will still be erect, because the rays belonging to each visible point will not intersect before they reach the eye. But in this case, the image becomes less and less distinct, at the same time that the visual angle is increasing; so that at the centre, or rather a little before, the image becomes confused and imperfect; owing to the small parts of the object subtending angles too large for distinct vision, just as happens when objects are viewed too near with the naked eye.

3. In the cases just considered, the images will appear erect, but in the case where the object is further from the mirror than its centre of concavity, the image will be inverted ; and the more distant the object is from the centre, the less will be its image, and the further from the said centre, or the nearer the focus, and the converse ; the image and object coinciding when the latter is stationed exactly at the centre, as noticed in the preceding case.

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12. What, if from a point between that focus and the centre ? 13. If from a point beyond the centre ? 14. If from the centre ? From what do these fourteen principles, stated above, result ?

In estimating these angles, it must be recollected, that no line is perpendicular to a convex or concave mirror, which will not, when sufficiently prolonged, pass through the centre of the sphere of which the mirror* is a portion.

SECTION XV.

Refraction of Light—Optics continued.

352. By the refraction of light is meant its being turned or bent from its course; and this always takes place when it passes *obliquely* from one medium to another.

By a medium,† in optics, is meant any substance through which light can pass. Thus, air, glass, water and other fluids, are media.

* Mirrors (or looking-glasses) may be made of polished metal, or glass, with the back covered with an amalgam, or mixture of mercury and tinfoil. It is the smooth and bright surface of the mercury that reflects the rays, the glass acting only as a transparent case or covering, through which the rays find an easy passage. Some of the rays are absorbed in their passage through the glass, because the purest glass is not free from imperfections. For this reason the best mirrors are made of fine and highly polished steel.

Concave mirrors, by the property which they possess of causing parallel rays to converge to a focus, are sometimes used as burning-glasses. M. Dufay made a concave mirror of plaster of Paris, gilt and burnished, 20 inches in diameter; with which he set fire to tinder, at the distance of fifty feet. But the most remarkable thing of the kind, on record, is the compound mirror, constructed by Buffon. He arranged one hundred and sixty-eight small plane mirrors in such a manner as to reflect radiant light and heat to the same focus, like one large concave mirror. With this apparatus he was able to set wood on fire at the distance of 209 feet, to melt lead at 100 feet, and silver at 50 feet.

† The plural number of this word is *media*, although *mediums* is sometimes used. A medium is called dense or rare, in optics, according to its refractive power, and not according to its specific gravity. Thus, alcohol, and many of the essential oils, although of less specific gravity than water, have a greater refracting power, and are, therefore, called denser media than water. In the following list, the various substances are enumerated in the order of their refractive power, or, in other words, in the order of their density, the last mentioned being the densest, and the first the rarest; namely, air, ether, ice, water, alcohol, alum, olive oil, oil of turpentine, amber, quartz, glass, melted sulphur, diamond.

How can you prove whether a line be perpendicular to a convex or a concave mirror? What is said with regard to mirrors in the note? Of what are the best mirrors made? For what are concave mirrors sometimes used? 352. What is meant by the refraction of light? When does this take place? What is a medium in optics? Give some examples of media? In what proportion is a medium dense or rare?

353. There are three fundamental laws of dioptrics, on which all its phenomena depend, namely:

First. When light passes from one medium to another, in a perpendicular direction, it passes on in a straight line without altering its course.

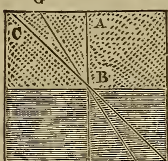
Second. When light passes in an oblique direction, from a *rarer* to a *denser* medium, it will be turned from its course and proceed through the denser medium *less* obliquely, and in a line nearer to a perpendicular to its surface.

Third. When light passes from a denser to a rarer medium, it passes through the rarer medium in a more oblique direction, and in a line further from a perpendicular to the surface of the denser medium.

Illustration. In Fig. 104 the line A B represents a ray of light passing from air into water, in a perpendicular direction. According to the first law, stated above, it will continue on in the same line through the denser medium to E. If the ray were to pass upward through the denser medium, the water, in the same perpendicular direction to the air, by the same law it would also continue on in the same straight line to A.

Fig. 104.

G



E F D

But if the ray proceed from a rarer to a denser medium, in an oblique direction, as from C to B, when it enters the denser medium it will not continue on in the same straight line to D, but, by the second law, stated above, it will be refracted or bent out of its course, and proceed in a less oblique direction to F, which is nearer the perpendicular A B E than D is.

Again, if the ray proceed from the denser medium, the water, to the rare medium, the air, namely, from F to B; instead of pursuing its straight course to G, it will be refracted, by the third law, above stated, and proceed in a more oblique direction to C, which is further from the perpendicular A B E than G is.

The refraction is more or less in all cases in proportion as the rays fall more or less obliquely on the refracting surface.

From what has now been stated, with regard to refraction, it will be seen that many interesting facts may be explained. Thus, an oar or a stick, when partly immersed in water, appears bent, because we see one part in one medium, and the other in another medium; the part which is in the water appears higher than it really is, on account of the refraction of the denser medium.

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353. What are the three fundamental laws of dioptrics? First? Second? Third? Illustrate the first rule by the line at B, in fig. 104. Illustrate the second rule by the line C B. Illustrate the third rule by the line F B. In what proportion does the refraction increase and diminish? Why does an oar or a stick, when partly immersed in water, appear bent? Why does the part which is in the water appear higher than it really is?

For the same reason, when we look *obliquely* upon a body of water it appears more shallow than it really is. But when we look *perpendicularly* downwards, from a boat, we are liable to no such deception, because there will be no refraction.

Let a piece of money be put into a cup or a bowl, and the cup and the eye be placed in such a position that the side of the cup will just hide the money from the sight, then keeping the eye still, let the cup be filled with water—the money will become distinctly visible.

354. The refraction of light prevents our seeing the heavenly bodies in their real situation.*

The light which they send to us is refracted in passing through the atmosphere, and we see the sun, the stars, &c. in the direction of the refracted ray. In consequence of this atmospheric refraction the sun sheds his light upon us earlier in the morning and later in the evening, than we should otherwise perceive it. And when the sun is actually below the horizon, those rays which would otherwise be dissipated through space, are refracted by the atmosphere towards the surface of the earth, causing twilight. The greater the density of the air the higher is its refractive power, and, consequently, the longer the duration of twilight.

355. When a ray of light passes from one medium to another, and through that into the first again, the two refractions being equal, and in opposite directions, no sensible effect is produced.

This explains the reason why the refractive power of flat window glass produces no effect on objects seen through it. The rays suffer two refractions, which, being in contrary directions, produce the same effect as if no refraction had taken place.

* There is another reason, also, why we do not see the heavenly bodies in their true situation. Light, though it moves with great velocity, is about 8 1-2 minutes in its passage from the sun to the earth, so that when the rays reach us, the sun has quitted the spot he occupied on their departure; yet we see him in the direction of those rays, and, consequently, in a situation which he abandoned eight minutes and a half before. The refraction of light does not affect the appearance of the heavenly bodies when they are vertical, that is, directly over our heads, because the rays then pass perpendicularly, a direction incompatible with refraction.

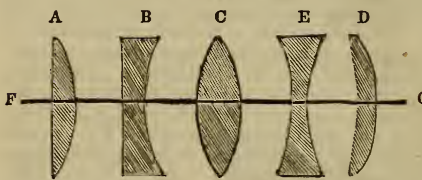
It may here also be remarked that it is entirely owing to the refraction of the atmosphere that the heavens appear bright in the day time. If the atmosphere had no refractive power, only that part would be luminous in which the sun is placed; and on turning our back to the sun, the whole heavens would appear as dark as in the night; we should have no twilight, but a sudden transition from the brightest sunshine to darkness, immediately upon the setting of the sun.

Why does a body of water, when viewed obliquely, appear more shallow than it really is? In what direction can we look so as to cause no refraction? What experiment is here related? 354. Why do we not see the heavenly bodies in their real situation? In what direction do we see them? What causes twilight? Upon what does the duration of twilight depend? What other reason is given, in the note, why we do not see the heavenly bodies in their true situation? When does the refraction of light not affect the appearance of the heavenly bodies? Why do the heavens appear bright in the day time? 355. What effect is produced when a ray of light passes from one medium to another, and through that into the first again? Why? Why does the refractive power of flat window-glass produce no effect on objects seen through it?

356. A lens is a glass, which, according to its peculiar form, causes the rays of light to converge to a focus, or disperses them further apart, according to the laws of refraction.

357. There are various kinds of lenses, named according to their focus; but they are all to be considered as portions of the internal or external surface of a sphere.

Fig. 105.



A single convex lens has one side flat and the other convex; as A in Fig. 105.

A single concave lens is flat on one side and concave on the other, as B in Fig. 105.

A double con-vex lens is convex on both sides, as C, Fig. 105.

A double concave lens is concave on both sides, as D, Fig. 105.

A meniscus is convex on one side and concave on the other, as E, Fig. 105.

The axis of a lens is a line passing through the centre; thus, F G, Fig. 105, is the axis of all the five lenses.

358. The peculiar form of the various kinds of lenses causes the light which passes through them to be refracted from its course. (*According to the laws stated in No.* 353.)

It will be remembered that, according to the laws stated in No. 353, light, in passing from a rarer to a denser medium, is *refracted* towards the perpendicular; and, on the contrary, that in passing from a denser to a rarer medium, that it is refracted further from the perpendicular. In order to estimate the effect of a lens, we must consider the situation of the perpendicular, with respect to the surface of the lens. Now, a perpendicular, to any convex or concave surface, must always, when prolonged, pass through the centre of sphericity; that is, in a lens, the centre of the circle of

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356. What is a lens? 357. How are all lenses to be considered? What is a single convex lens? What part of fig. 105 represents a single convex lens? What is a single concave lens? What part of fig. 105 represents a single concave lens? What is a double convex lens? What part of fig. 105 represents a double convex lens? What is a double concave lens? What part of fig. 105 represents a double concave lens? What is a meniscus? What part of fig. 105 represents a meniscus? What is the axis of a lens? What line, in fig. 105 represents the axis of all the five lenses? 358. What is stated in No. 358 with regard to the form of the lenses? How is light refracted in passing from a rarer to a denser medium? How, in passing from a denser to a rarer? What must be considered in estimating the effect of lenses? Through what must a perpendicular, to any convex or concave surface, always, when prolonged, pass?

which the lens is a portion. By an attentive observation, therefore, of the laws above stated, and of the situation of the perpendicular on *each* side of the lens, it will be found *in general*,—

First, That CONVEX lenses collect the rays into a focus, and, consequently, magnify objects at a certain distance.

Second, That CONCAVE lenses disperse the rays, and, consequently, diminish objects seen through them.

359. The focal distance of a lens is the distance from the middle of the glass to the focus. This, in a single convex lens, is equal to the diameter of the sphere of which the lens is a portion; and in a double convex lens is equal to the radius of a sphere of which the lens is a portion.

360. When parallel rays* fall on a convex lens, that only which falls in the direction of the axis of the lens is perpendicular to its surface, and will continue on in a straight line through the lens. The other rays, falling obliquely, are refracted to the axis and will meet in a focus.

It is this property of a convex lens which gives it its power as a burning glass. All the parallel rays of the sun which pass through the glass, are collected together in the focus; and, consequently, the heat at the focus is to the common heat of the sun, as the area of the glass is to the area of the focus. Thus, if a lens, four inches in diameter, collect the sun's rays into a focus, at the distance of twelve inches, the image will not be more than one tenth of an inch in diameter; the surface of this little circle is 1600 times less than the surface of the lens, and, consequently, the heat will be 1600 times greater at the focus than at the lens. †

* The rays of the sun are considered parallel at the surface of the earth.

† The following effects were produced by a large lens, or burning glass, two feet in diameter, made at Leipsic, in 1691. Pieces of lead and tin were instantly melted; a plate of iron was soon rendered red hot, and afterwards fused, or melted, and a burnt brick was converted into yellow glass. A double convex lens, three feet in diameter, and weighing 212 pounds, made by Mr. Parker, in England, melted the most refractory substances. Cornelian was fused in 75 seconds, a crystal pebble in 6 seconds, and a piece of white agate in 30 seconds. This lens was presented by the King of England to the Emperor of China.

What is stated with regard to convex lenses? What, with regard to concave lenses? 359. What is the focal distance of a lens? To what is this equal in a single convex lens? To what is it equal in a double convex lens? 360. When parallel rays fall on a convex lens, which one is perpendicular to its surface? How are the other rays, falling obliquely, refracted? What property of a convex lens, gives it its power as a burning glass? Where are all the parallel rays of the sun, which pass through the glass, collected? How does the heat at the focus compare with the common heat of the sun? What is related in the note with regard to the effects of lenses produced by burning glasses?

361. The following effects result from the laws of refraction, stated in No. 353; and, first, with regard to CONVEX surfaces.

1. Parallel rays passing out of a rarer into a denser medium, through a CONVEX surface, will become converging.
2. Diverging rays will be made to diverge less, to become parallel, or to converge, according to the degree of divergency before refraction, or of the convexity of the surface.
3. Converging rays, towards the centre of convexity, will suffer no refraction.
4. Rays converging to a point beyond the centre of convexity, will be made more converging.
5. Converging rays towards a point nearer the surface than the centre of convexity, will be made less converging by refraction.

[*When the rays proceed out of a* DENSER *into a* RARER *medium, the reverse occurs in each case.*]

Secondly. With regard to CONCAVE *Surfaces.*

6. Parallel rays, proceeding out of a rarer into a denser medium, through a CONCAVE surface, are made to diverge.
7. Diverging rays are made to diverge more—to suffer no refraction—or to diverge less, according as they proceed from a point beyond the centre, from the centre, or between the centre and the surface.
8. Converging rays are made less converging, parallel, or diverging, according to their degree of convergency before refraction.*

[*When the rays proceed out of a denser into a rarer medium, the reverse takes place in each case.*]

362. Double convex, and double concave glasses, or lenses, are used in spectacles, to remedy the defects of the eye, when by age it becomes too flat, or loses a portion of its roundness; or when by any other cause it assumes too round a form, as in the case of short sighted, (or, as they are sometimes called, nearsighted)

* The above eight principles are all the necessary consequence of the operation of the three laws mentioned in number 353. The reason that so many different principles are produced, by the operation of those laws, is, that the perpendiculars to a convex or concave surface are constantly varying, so that no two are parallel. But in flat surfaces the perpendiculars are parallel; and one invariable result is produced by the rays when passing from a rarer to a denser, or from a denser to a rarer medium, having a flat surface.

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361. 1. What is the first effect related as resulting from the laws of refraction, stated in No. 345, with regard to convex surfaces? 2. What is said of diverging rays? 3. What is said of converging rays towards the centre of convexity? 4. What of rays converging to a point beyond the centre of convexity? 5. What of rays converging to a point nearer the surface than the centre of convexity? When the rays proceed out of a denser into a rarer medium, what occurs? 6. What is stated, in No. 6, with regard to concave surfaces? 7. What is said of diverging rays? 8. What is said of converging rays? Of what are the above eight principles the necessary consequence? What is the reason that so many different principles are produced by the operation of these laws? 362. For what are double convex and concave glasses, or lenses, used in spectacles?

persons. Convex glasses are used when the eye is too flat, and concave glasses when it is too round.*

363. The eye is composed of a number of coats, or coverings, within which are enclosed a lens, and certain humors, in the shape, and performing the office of convex lenses.

364. The different parts of the eye are: 1. The Cornea. 2. The Iris. 3. The Pupil. 4. The Aqueous Humor 5. The Crystalline Lens. 6. The Vitreous Humor. 7. The Retina. 8. The Choroid. 9. The Sclerotica. 10. The Optic Nerve.

Fig. 106.

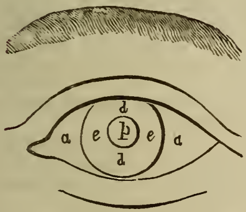


Illustration. Fig. 106 represents a front view of the eye, in which *a a* represents the cornea, or, as it is commonly called, the white of the eye; *e e* is the Iris, which is of different colors in different persons; and we call a person's eye black, blue, &c. according to the color of the Iris. The Iris has a circular opening in the centre, called the pupil, *p*, which contracts in a strong light, and expands in a faint light, and thus regulates the quantity which is admitted to the tender parts in the interior of the eye.

Fig. 107.

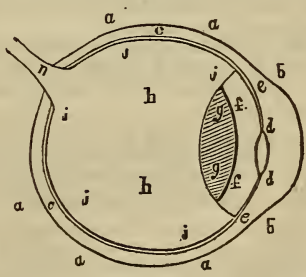


Fig. 107 represents a side view of the eye, laid open, in which *b b* represents the cornea, *e e* the Iris, *d d* the pupil, *f f* the aqueous humor, *g g* the crystalline lens, *h h* the vitreous humor, *i i i i* the Retina, *c c* the choroid *a a a a* the sclerotica, and *n* the optic nerve.

The cornea forms the anterior portion of the eye. It is set in the sclerotica in the same manner as a crys-

* These lenses or glasses are generally numbered by opticians, according to their degree of convexity or concavity; so that by knowing the number that fits the eye, the purchaser can generally be accommodated without the trouble of trying many glasses

What glasses are used when the eye is too flat? What are used when the eye is too round? 363. Of what is the eye composed? 264. What are the different parts of the eye? First? Second? Third? Fourth? Fifth? Sixth? Seventh? Eighth? Ninth? Tenth? What does fig. 106 represent? Explain the fig. What does fig. 107 represent? Explain the fig. What part of the eye does the cornea form?

tal of a watch is set in the case. Its degree of convexity varies in different individuals and in different periods of life. As it covers the pupil and the iris, it protects them from injury. Its principal office is to cause the light which reaches the eye, to converge to the axis. Part of the light, however, is reflected by its finely polished surface, and causes the brilliancy of the eye.

The Iris is so named from its being of different colors. It is a kind of circular curtain, placed in the front of the eye to regulate the quantity of light passing to the back part of the eye. It has a circular opening in the centre, which it involuntarily enlarges or diminishes.

The pupil is merely the opening in the iris, through which the light passes to the lens behind. It is always circular in the human eye, but in quadrupeds it is of different shape. When the pupil is expanded to its utmost extent it is capable of admitting ten times the quantity of light that it does when most contracted.* In cats and other animals, which are said to see in the dark, the power of dilatation and contraction is much greater; it is computed that their pupils may receive one hundred times more light at one time than at another. The light only, which passes the pupil, can be of use in vision; that which falls on the iris is reflected, returns through the cornea, and exhibits the color of the iris.

The aqueous humor is a watery fluid,† as clear as the purest water. In shape it resembles a meniscus, and, being situated between the cornea and the crystalline lens, it assists in collecting and transmitting the rays of light from external objects to that lens.

The crystalline lens is a transparent body, in the form of a double convex lens, placed between the aqueous and vitreous humors. Its office is not only to collect the rays to a focus, on the retina, but also to increase the intensity of the light which is directed to the back part of the eye.

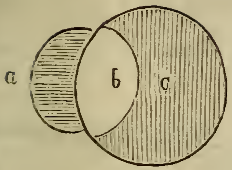
The vitreous humor (so called from its resemblance to melted glass,) is a perfectly transparent mass, occupying the globe of the eye. Its shape is like a meniscus, whose convexity greatly exceeds the concavity.

* When a person comes from a dark place into a strong light, the eyes suffer pain, because, the pupil being expanded, admits a larger quantity of light to rush in, before it has had time to contract. And when we go from a strong light into a faint one, we at first imagine ourselves in darkness, because the pupil is then contracted, and does not *instantly* expand.

† The author is aware of the tautology in this expression, but as he is writing for the instruction of children, and unlettered persons, he deems it necessary to make his explanations as simple as possible.

Is its degree of convexity the same in all persons and all periods of life? What is its principal office? From what does the iris take its name? What is the use of the iris? What is the pupil? What is its form in the human eye? How much more light is the pupil capable of admitting, when expanded to its utmost extent, than when most contracted? What is said of those animals which are said to see in the dark? What light, only, is of use in vision? What becomes of the light which falls on the iris? What is the aqueous humor? What is its form? Of what use is it? What is the crystalline lens? What is its office? What is the vitreous humor? Why do persons sometimes experience pain when passing from a dark place into strong light? What is the shape of the vitreous humor?

Fig. 108.



In Figure 108 the shape of the aqueous and vitreous humors, and the crystalline lens is presented. *a* is the aqueous humor, which is a meniscus, *b* the crystalline lens, which is a double convex lens, and *c* the vitreous humor, which is, also, a meniscus, whose concavity has a smaller radius than its convexity.

The retina is the seat of vision or sight. The rays of light being refracted in their passage by the other parts of the eye, are brought to a focus in the retina, where an inverted image of the object is represented.

The choroid is the inner coat or covering of the eye. Its outer and inner surface is covered with a substance called the *pigmentum nigrum*, (or black paint.) Its office is, apparently, to absorb the rays of light immediately after they have fallen on the retina. It is the opinion of some philosophers that it is the choroid and not the retina, which conveys the sensation produced by rays of light to the brain.

The sclerotica is the outer coat of the eye. It derives its name from its hardness. Its office is to preserve the globular figure of the eye, and defend its more delicate internal structure. To the sclerotica are attached the muscles which move the eye. It receives the cornea, which is inserted in it somewhat like a watch glass in its case. It is pierced by the optic nerve, which, passing through it, expands over the inner surface of the choroid, and thus forms the retina.

The optic nerve is the organ which carries the impressions made by the rays of light; (whether by the medium of the retina or the choroid,) to the brain, and thus produces the sensation of sight.*

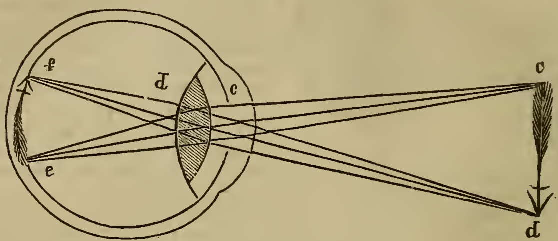
365. The eye is a natural *camera obscura*, and the images of all objects seen by the eye are represented on the retina, in the same manner as the forms of external objects are delineated in that instrument. (*See No.* 339, *note.*)

* For the above description of the eye and its parts, the author is mainly indebted to Paxton's Introduction to the Study of Anatomy, edited by Dr. Lewis of this city.

Explain fig. 108. What is the retina? What is the choroid? By what is its outer and inner surface covered? What is its office? What is the opinion of some philosophers with regard to the choroid? What is the sclerotica? From what does it derive its name? What is its office? What are attached to the sclerotica? What is the optic nerve? 365. What is stated, in No. 365, with regard to the representations on the retina of the images of all objects seen by the eye?

Fig. 109 represents only those parts of the eye which are most essential. The image is formed thus. The rays from the object *c d*, diverging toward the eye, enter the cornea *c*, and cross one another in their passage, through the crystalline lens *d*, by which they are

Fig. 109.



made to converge on the retina, where they form the inverted* image, *f e*.

366. **The convexity of the crystalline humor is increased or diminished by means of two muscles to which it is attached. By this means the focus of the**

* Although the image is inverted on the retina, we see objects *erect*, because all the images, formed on the retina have the same relative position which the objects themselves have; and as the rays all cross each other, the eye is directed upwards, to receive the rays which proceed from the upper part of an object, and downwards, to receive those which proceed from the lower part.

A distinct image is also formed on the retina of each eye; but as the optic nerves of the two eyes unite, or cross each other before they reach the brain, the impressions received by the two nerves are united, so that only one idea is excited, and objects are seen single. Although an object may be distinctly seen with only one eye, it has been calculated that the use of *both* eyes makes a difference of about one twelfth.

From the description now given of the eye, it may be seen what are the defects which are remedied by the use of concave and convex lenses; and how the use of these lenses remedies them. When the crystalline humor of the eye is too round, the rays of light, which enter the eye, are converged to a focus *before* they reach the retina, and, therefore, the image will not be distinct; and when the crystalline humor is too *flat*, (as is often the case with old persons,) the rays will not be converged on the retina, but tend to a point beyond it. A convex glass, by assisting the convergency of the crystalline lens, brings the rays to a focus on the retina, and produces distinct vision.

The eye is also subject to imperfection by reason of the humors losing their transparency, either by age or disease. For these imperfections no glasses offer a remedy without the aid of surgical skill. The operation of couching and removing cataracts from the eye consists in making a puncture or incision through which the diseased part may escape. Its office is then supplied by a lens. If, however, the operator, by accident or want of skill, permits the vitreous humor to escape, the globe of the eye immediately diminishes in size, and total blindness is the inevitable result.

Explain fig. 109. Why do the objects appear erect when the images are inverted? Why do we see only one image, when an image is formed on both eyes? What are the defects which are remedied by the use of concave and convex lenses? In what other way is the eye subject to imperfection? Is there any remedy for this? 366. By what is the convexity of the crystalline humor increased or diminished?

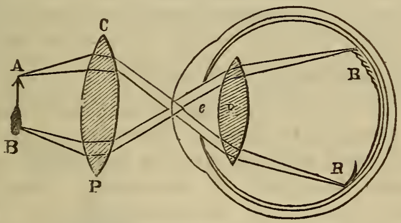
rays which pass through it, constantly falls on the retina; and an equally distinct image is formed, both of distant objects and those which are near.

367. A single microscope consists simply of a convex lens, commonly called a magnifying glass; in the focus of which the object is placed, and through which it is viewed.

By means of a microscope the rays of light from an object are caused to diverge less; so that when they enter the pupil of the eye they fall parallel on the crystalline lens, by which they are refracted to a focus on the retina.

Fig. 110 represents a convex lens, or single microscope, C P. The diverging rays from the object A B are refracted in their passage through the lens C P, (*See* 2 *under No.* 361,) and made to

Fig. 110.



fall parallel on the crystalline lens, by which they are refracted to a focus on the retina R R; and the image is thus magnified, because the divergent rays are collected by the lens and carried to the retina.

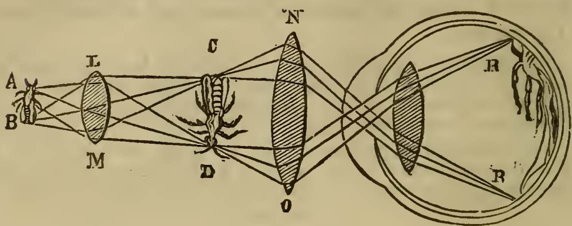
Those lenses or microscopes which have the shortest focus, have the greatest magnifying power; and those which are the most bulging or convex, have the shortest focus. But as the protuberance of a large lens prevents the eye from approaching very near to an object, this inconvenience is remedied by making the lens exceedingly small. It may then be spherical without occupying much space, and thus unite the advantages of a short focus, and of allowing the eye to approach very near to an object.

368. A double microscope consists of two convex lenses, by one of which a magnified image is formed, and by the other this image is carried to the retina of the eye.

What is effected by this means? 367. What is a single microscope? What is the use of this microscope? What fig. represents a microscope? Explain the figure. What lenses have the greatest magnifying power? What lenses have the shortest focus? Of what does a double microscope consist? What is the use of these two lenses?

Fig. 111 represents the effect produced by the lenses of a double microscope. The rays which diverge from the object A B are collected by the lens L M, (called the object glass, because it is nearest to the object,) and form an inverted magnified image at C D.

Fig. 111.



The rays which diverge from this image are collected by the lens, N O, (called the eye glass, because it is nearest to the eye,) which acts on the principle of the single microscope, and forms a still more magnified image on the retina R R.

369. The solar microscope, is a microscope with a mirror attached to it, upon a moveable joint, which can be so adjusted as to receive the sun's rays and reflect them upon the object. It consists of a tube, a mirror or looking glass, and two convex lenses. The sun's rays are reflected by the mirror through the tube upon the object; the image of which is thrown upon a white screen, placed at a distance to receive it.

The microscope, as above described, is used for viewing transparent objects only. When opaque objects are to be viewed, a mirror is used to reflect the light on the side of the object; the image is then formed by light reflected *from* the object, instead of being transmitted through it.

The magnifying power of a single microscope is ascertained by dividing seven inches, the least distance at which an object can be seen by the naked eye, by the focal distance of the lens. Thus, if the focal distance of a lens be only the 1-4 of an inch, then the *diameter* of an object will be magnified 28 times, (because 7, divided by 1-4, is the same as multiplying 7 by 4,) and the *surface* will be magnified 784 times.

What does fig. 111 represent? Explain the figure. 369. What is the solar microscope? Of what does it consist? By what, in this microscope, are the sun's rays reflected, and upon what? For viewing what objects, only, is the microscope, above described, used? How do those microscopes used for viewing opaque objects, differ from these? How is the image then formed? How is the magnifying power of a single microscope ascertained? Illustrate this.

The magnifying power of the compound microscope is found in a similar manner, by ascertaining the magnifying power first of one lens, and then of the other.

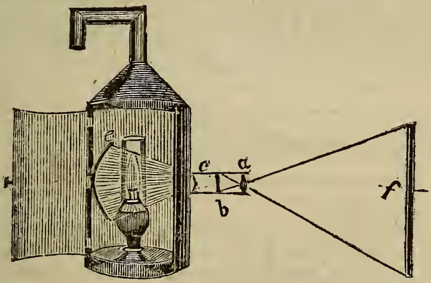
The magnifying power of the solar microscope is in proportion as the distance of the image, from the object glass, is greater than that of the object itself from it. Thus, if the distance of the object from the object glass be 1-4 of an inch, and the distance of the image, or picture, on the screen, be ten feet, or 120 inches, the object will be magnified in length 480 times, or, in surface, 230,000 times.*

370. The magic lantern is an instrument constructed on the principle of the solar microscope, with this difference, that the light is supplied by a lamp instead of the sun.

The objects to be viewed by the magic lantern are generally painted with transparent colors, on glass slides, which are received into an opening in the front of the lantern. The light from the lamp, in the lantern, passes through them, and carries the pictures, painted on the slides, through the lenses, by means of which a magnified image is thrown upon the wall, on a white surface prepared to receive it.

Fig. 112 represents the magic lantern. The rays of light from the lamp are received upon the concave mirror *e*, and reflected to

Fig. 112.



the convex lens *c*, which is called the condensing lens, because it concentrates a large quantity of light upon the object painted on the

* A lens may be caused to magnify or to diminish an object. If the object be placed at a distance from the focus of a lens, and the image be formed in or near the focus, the image will be diminished; but if the object be placed near the focus, the image will be magnified.

How is the magnifying power of the compound microscope ascertained? In what proportion is the magnifying power of the solar microscope? Illustrate this. How may a lens be made to magnify or diminish an object? 370. What is the magic lantern? What figure represents a magic lantern? Explain the figure. In what proportion will the size of the image increase or diminish?

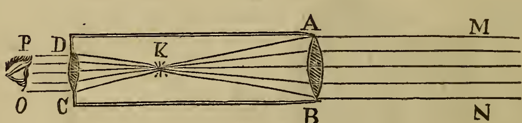
slide, inserted at *b*. The rays from the illuminated object at *b* are carried divergent through the lens *a*, forming an image on the screen at *f*. The image will increase or diminish in size, in proportion to the distance of the screen from the lens *a*.

371. A telescope is an instrument for viewing distant objects. There are two kinds of telescopes, namely, the refracting telescope and the reflecting telescope. A refracting telescope is one in which the object itself is viewed, through the medium of a number of lenses. A reflecting telescope is one in which the image of the object is reflected from a concave mirror, within the tube of the telescope, and viewed through a number of lenses.*

There are two kinds of refracting telescopes, called the astronomical telescope, or night glass, and the terrestial telescope, or day glass.† In the former, or night glass, there are but two lenses or glasses, but the object is viewed in an inverted position. As the glass is used principally for viewing the heavenly bodies, the inversion of the image produces no inconvenience. In the latter, or day glass, two additional lenses are introduced to give the image its natural position.

Fig. 113 represents a night glass, or astronomical telescope. It consists of a tube, A B C D, containing two glasses, or lenses. The lens A B, having a longer focus, forms the object glass; the other lens, D C, is the eye glass. The rays from a very distant body,

Fig. 113.



as a star, and which may be considered parallel to each other, are refracted by the object glass A B to a focus at K. The image is then seen through the eye glass D C magnified as many times as the focal length of the eye glass is contained in the focal length of the

* The image of the object seen through a refracting telescope is never so clear and perfect as that obtained by the reflecting telescope; because the dispersion of colors which every lens produces, in a greater or less degree, renders the image dull and indistinct, in proportion to the number of lenses employed.

† Some glasses or telescopes are marked " Night and Day." These have four glasses, two of which can be removed when the heavenly bodies are viewed.

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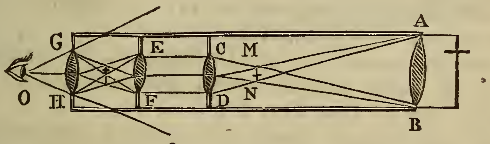
371. What is a telescope? How many kinds of telescopes are there? What are they? What is a refracting telescope? What is a reflecting telescope? Why is the image of an object, seen through a refracting telescope, less clear and perfect than when seen through a reflecting telescope? How many kinds of refracting telescopes are there? What are they? How do they differ, the one from the other? What does figure 113 represent? Explain the figure.

object glass. Thus, if the focal length of the eye glass, D C, be contained 100 times in that of the object glass, A B, the star will be seen magnified 100 times. It will be seen by the figure that the image is inverted; for the ray M A, after refraction, will be seen in the direction C O, and the ray N B, in the direction D P.

Fig. 114 represents a day glass or terrestrial telescope, commonly called a spy glass. This, likewise, consists of a tube, A B H G, containing four lenses, or glasses, namely, A B, C D, E F and G H. The lens A B is the object glass, and G H the eye glass. The two additional eye glasses, E F and C D, are of the same size and

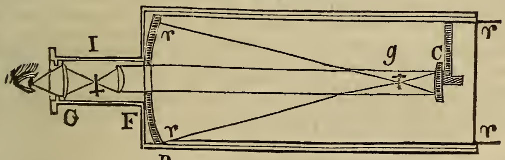
Fig. 114.



shape, and placed at equal distances from each other, in such a manner that the focus of the one meets that of the next lens. These two eye glasses, E F and C D, are introduced for the purpose of collecting the rays proceeding from the inverted image M N into a new upright image, between G H and E F, and the image is then seen through the last eye glass G H under the angle of vision, P O Q.

Fig. 115 represents a reflecting telescope. This consists also of a large tube, containing two concave metallic mirrors, (*See number* 349,) A B and C, with two plano-convex eye glasses. The mir-

Fig. 115.



rors are placed at a little more than the sum of their focal distance from each other. The parallel rays *r r*, coming from a distant object, are reflected to a focus *g* by the concave mirror, A B, and thus form an inverted image at *g*; the diverging rays proceeding from this image are again reflected by the small mirror C, and received by the eye glass F, through a hole in the middle of the mirror A B. The eye glass F collects these reflected rays into a new image, at I and this image is seen magnified through the second eye glass, G.

What does fig. 114 represent? Explain the figure. What does fig. 115 represent? Explain the figure.

In reflecting telescopes, mirrors are used to bring the image near the eye, and a lens or eye glass to magnify the image.

The advantage of the reflecting telescope, is, that mirrors, whose focus is six feet, will magnify as much as lenses whose focus is a hundred feet.

372. That part of the science of optics which relates to colors is called Chromatics.

Colors do not exist in the bodies themselves, but are caused by the peculiar manner in which the light is reflected from their surfaces. [*See No.* 21.]

373. Light is composed of rays of different colors, which may be separated by a prism.*

374. A prism is a solid triangular, or three-sided piece of highly polished glass, generally six or eight inches long.† [*See Fig.* 116.]

375. The colors which enter into the composition of light are seven, namely, red, orange, yellow, green, blue, indigo, and violet. Each of these have different degrees of refrangibility.

376. When light is made to pass through a prism, the different colored rays are separated, and form an image on a screen or wall, in which the colors will be arranged in the order in which they are enumerated in No. 375.

Illustration. Fig. 116 represents rays of light passing from the aperture, in a window-shutter, A B, through the prism P. Instead of continuing in a straight course to E, and there forming an image, they will be refracted, in their passage through the prism, and form an image on the screen, C D. But as the different colored rays have different degrees of refrangibility, (*See No.* 352,) or, in other words, suffer different degrees of refraction, those which are refracted the least will fall upon the lowest part of the screen, and

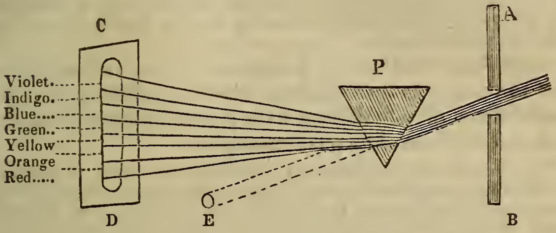
* This discovery was made by Sir Isaac Newton.

† A prism may be made of three pieces of plate glass, about six or eight inches long, and two or three broad, joined together at their edges, and made water tight by putty. The ends may be fitted to a triangular piece of wood, in one of which an aperture is made by which to fill it with water, and thus to give it the appearance and the refractive power of a solid prism.

Why are mirrors used in reflecting telescopes? What is the use of the lens? What is the advantage of the reflecting telescope? 372. What is chromatics? What causes color? 373. Of what is light composed? How can these rays be separated? By whom was this discovery made? 374. What is a prism? How may a prism be made? 375. How many colors enter into the composition of light? What are they? Do these rays all have the same degree of refrangibility? 376. What takes place when light is made to pass through a prism?

those which are refracted the most will fall upon the highest part. The red rays, therefore, suffering the smallest degree of refraction,

Fig. 116.



fall on the lowest part of the screen, and the remaining colors are arranged in the order of their refraction.*

If the colored rays, which have been separated by a prism, fall upon a convex lens, they will converge to a focus, and appear white. Hence, it appears, that white is not a simple color, but is produced by the union of several colors.

The spectrum, formed by a prism, being divided into 360 parts, it is found that the red occupies 45 of those parts, the orange 27, the yellow 48, the green 60, the blue 60, the indigo 40, and the violet 80. By mixing the seven primitive colors in these proportions, a white is obtained ; but, on account of the impurity of all colors, it will be of a dingy hue. If the colors were more clearly and accurately defined, the white, thus obtained, would appear more pure also. An experiment to prove what has just been said may be thus per-

* It is supposed that the red rays are refracted the least, on account of their greater momentum, and that the blue, indigo, and violet are refracted the most, because they have the least momentum. The same reason, it is supposed, will account for the red appearance of the sun, through a fog, or at rising and setting. The increased quantity of the atmosphere, which the oblique rays must traverse, and its being loaded with mists and vapors, which are usually formed at those times, prevents the other rays from reaching us.

A similar reason will account for the blue appearance of the sky. As these rays have less momentum, they cannot traverse the atmosphere so readily as the other rays, and they are, therefore, reflected back to our eyes by the atmosphere. If the atmosphere did not reflect any rays the skies would appear perfectly black.

Explain figure 116. Why do the red rays fall on the lowest part of the screen? What is supposed with regard to the red rays? What, with regard to the blue, indigo and violet rays? Why does the sun appear red through a fog? Why does the sky appear of a blue color? What would be the appearance of the sky if the atmosphere did not reflect any rays? Is white a simple color? How is it produced? The spectrum formed by a prism, being divided into 360 parts, how many of these parts does the red occupy? The orange? The yellow? The green? The blue? The indigo? The violet?

formed. Take a circular piece of board, or card, and divide it into parts, by lines drawn from the centre to the circumference. Then, having painted the seven colors in the proportions above named, cause the board to revolve rapidly around a pin or wire at the centre. The board will then appear of a white color. From this it is inferred that the whiteness of the sun's light arises from a due mixture of all the primary colors.

The colors of all bodies are either the simple colors, as refracted by the prism, or such compound colors as arise from a mixture of two or more of them.*

377. The rainbow is produced by the refraction of the sun's rays in their passage through a shower of rain; each drop of which acts as a prism in separating the colored rays, as they pass through it.

This is proved by the following considerations. *First*, A rainbow is never seen except when rain is falling, and the sun shining at the same time; and that the sun and the bow are always in opposite parts of the heavens; and, *secondly*, that the same appearance may be produced artificially, by means of water thrown into the air, when the spectator is placed in a proper position, with his back to the sun; and, *thirdly*, that a similar bow is generally produced by the spray which arises from large cataracts, or waterfalls, such, for instance, as the Falls of Niagara.

378. The color of all bodies depends upon the rays which they reflect.

Some bodies absorb all the rays which they receive except the red rays. These bodies, therefore, appear of a red color—some reflect the green, and absorb all the others—these will appear of a green color; and, in general, bodies appear of the color of those rays which they reflect, while they absorb all the other rays. Sometimes a body reflects a portion of the rays of several colors. The body will then appear of a compound color, composed of the various colors which it reflects. When a body reflects *all* the rays, it appears *white*—when it absorbs all the rays, it appears black. White, then, is a mixture of all the primitive colors, and black is the deprivation of all color.

From what has now been said it appears that no body has a permanent or intrinsic color of its own—but that color, as well as weight, are *accidental*, and not essential properties. (*See No.* 21, *page* 7.) All substances appear of the same color, or rather, more properly speaking, are deprived of all color, in the dark. Light, from whatever source it proceeds, is of the same nature, composed

* From the experiments of Dr. Wollaston, it appears that the seven colors, formed by the prism, may be reduced to four, namely, red, green, blue and violet; and that the other colors are produced by combinations of these.

What are the colors of all bodies? What appears from the experiments of Dr. Wollaston? 377. How is the rainbow produced? How is this proved? First? Second? Third? 378. Upon what does the color of all bodies depend? Of what color do bodies generally appear? When will a body appear of a compound color? Of what color will a body appear that reflects all the rays? When will a body appear black? Is color an essential property of a body?

of the various colored rays; and although some substances appear differently by candle-light from what they appear by day, this result may be supposed to arise from the weakness or want of purity in artificial light.

There can be no light without colors, and there can be no colors without light.

That the above remarks, in relation to the colors of bodies, are true, may be proved by the following simple experiment. Place a colored body in a dark room, in a ray of light that has been refracted by a prism; the body, of whatever color it naturally is, will appear of the color of the ray in which it is placed; for, since it receives no other colored rays, it can reflect no others.*

379. A multiplying glass is a convex lens, one side of which is ground down into several flat surfaces.

When an object is viewed through a multiplying glass, it will be multiplied as many times as there are flat surfaces on the lens. Thus, if one lighted candle be viewed through a lens, having twelve flat surfaces, twelve candles will be seen through the lens. The principle of the multiplying glass is the same with that of a convex or concave lens.

380. The Kaleidescope† consists of two reflecting surfaces, or pieces of looking-glass, inclined to each other at an angle of 60 degrees, placed between the eye and the objects intended to form the picture.

These two plates are enclosed in a tin or paper tube, and the objects, consisting of pieces of colored glass, beads, or other highly

* Although bodies, from the arrangement of their particles, have a tendency to absorb some rays, and reflect others, they are not so uniform in their arrangement as to reflect only pure rays of one color, and perfectly absorb all others; it is found, on the contrary, that a body reflects, in great abundance, the rays which determine its color, and the others, in a greater or less degree, in proportion as they are nearer or further from its color, in the order of refrangibility. Thus, the green leaves of a rose will reflect a few of the red rays, which will give them a brown tinge. Deepness, or darkness of color, proceeds from a deficiency rather than from an abundance of reflected rays. Thus, if a body reflects only a few of the green rays, it will appear of a dark green. The brightness and intensity of a color shows that a great quantity of rays are reflected. That bodies sometimes change their color, is owing to some chemical change, which takes place in the internal arrangement of their parts, whereby they lose their tendency to reflect certain colors, and acquire the power of reflecting others.

† The word Kaleidescope is derived from the Greek language, and means "The sight of a beautiful form." The instrument was invented by Dr. Brewster, of Edinburgh, a few years ago.

Of what color do bodies appear in the dark? Why do some bodies appear differently by candle-light? What is necessary to produce color? What experiments are related to prove the truth of the above? What rays does a body reflect in the greatest abundance? In what proportion does it reflect the other rays? Why do the green leaves of a rose appear to have a brown tinge? What does the brightness and intensity of a color show? Why do some bodies change their color? 379. What is a multiplying glass? How many times will an object, viewed through a multiplying glass, be multiplied? What is the principle of the magnifying glass? 380. Of what does the kaleidescope consist? From what is the word kaleidescope derived, and what does it mean? By whom was the instrument invented? What is here said with regard to the kaleidescope?

colored fragments, are loosely confined between two circular pieces of common glass, the outer one of which is slightly ground, to make the light uniform. On looking down the tube through a small aperture, and where the ends of the glass plates nearly meet, a beautiful circular figure will be seen, having six angles, the reflectors being inclined the sixth part of a circle. If inclined the twelfth part, or twentieth part of a circle, twelve or twenty angles will be seen. By turning the tube so as to alter the position of the colored fragments within, these beautiful forms will be changed; by which an almost infinite variety of patterns may be produced.

SECTION XVI.

Electricity.

381. The word Electricity* is a term used by philosophers to signify the operations of a very subtle and elastic fluid, which pervades the material world.

382. Electricity can be seen only in its effects; which are exhibited in the form of attraction and repulsion.

If a piece of amber, or sealing-wax, or a piece of smooth glass, perfectly clean and dry, be briskly rubbed with a dry woollen cloth, and immediately afterwards be held over small and light bodies,

* This word is derived from a Greek word, which signifies amber, because this substance was supposed to possess, in a remarkable degree, the property of producing the fluid, when excited or rubbed. The property itself was first discovered by Thales, of Miletus, one of the seven wise men of Greece. The word is now used to express both the fluid itself, and the science which treats of it.

The nature of electricity, is entirely unknown. Some philosophers consider it a fluid; others consider it as two fluids of opposite qualities; and others again deny its materiality, and deem it, like attraction, a mere property of matter. In this volume the opinion of Dr. Franklin is adopted, who supposed it to be a *single* fluid, disposed to diffuse itself equally among all substances; and exhibiting its peculiar effects only when a body by any means became possessed of more or less than its proper share. That when any substance has more than its natural share it is said to be *positively* electrified, and that when it has less than its natural share it is said to be *negatively* electrified,—that *positive* electricity implies a redundancy, and negative electricity a deficiency of the fluid

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381. What is electricity? What is stated in the note with regard to the word electricity? By whom was this property first discovered? What is stated with regard to the nature of electricity? Whose and what opinion is adopted in this volume? When is a substance said to be positively electrified? When is it said to be negatively electrified? What does positive electricity imply? What does negative electricity imply? 382. How can electricity be seen? How are these effects exhibited?

such as pieces of paper, thread, cork, straw, feathers or fragments of gold leaf, strewed upon a table, these bodies will be attracted, and fly towards the surface that has been rubbed, and adhere to it for a certain time. The surfaces that have acquired this power of attraction are said to be *excited;* and the substances thus susceptible of being excited are called *electrics*, while those which cannot be excited in a similar manner are called *non-electrics.*

383. The science of electricity, therefore, divides all substances into two kinds; namely, *Electrics*, or those substances which can be excited, and *Non-electrics*, or those substances which cannot be excited.

384. The electric fluid is readily communicated from one substance to another. Some substances, however, will not allow it to pass through them, while others give it a free passage. Those substances, through which it passes without obstruction, are called *conductors;* while those through which it cannot readily pass are called *non-conductors;* and it is found, by experiment, that all *electrics* are *non-conductors*, and all *non-electrics* are good *conductors* of electricity.

The following substances are *electrics*, or non-conductors of electricity; namely, the atmospheric air, (when dry,) glass, feathers, amber, diamond, and all precious stones, all gums and resins, the oxides of all metals, bees-wax, sealing-wax, sulphur, silk, wool, hair, paper, cotton. All these substances must be dry, or they will become more or less conductors.

The following substances are non-electrics, or conductors of electricity; namely, all metals, charcoal, living animals, vapor or steam.

The following are imperfect conductors, (that is, they conduct the electric fluid, but not so readily as the substances above mentioned,) namely, water, green vegetables, damp air, wet wood, and all substances containing moisture, common wood, dead animals, bone, horn, &c.

385. When a conductor, that is, a substance which can conduct electricity, is on all sides surrounded by non-conducting substances, it is said to be *insulated.*

What illustration of this is given? What is said of the surfaces which have acquired the power of attraction? What are electrics? What are non-electrics? 383. Into how many kinds does the science of electricity divide all substances? What are they? 384. What is said with regard to the communication of the electric fluid from one substance to another? Will all substances allow it to pass through them? What bodies are called conductors? What bodies are called non-conductors? What has been found, by experiment, with regard to electrics and non-electrics? What substances are electrics or non-conductors? Why must these substances be dry? What substances are non-electrics or conductors? What substances are mentioned as imperfect conductors? 385. When is a substance said to be insulated?

As glass is a non-conducting substance, any conducting substance surrounded with glass, or standing on a table or stool, with glass legs, will be *insulated*.

As the air is a non-conductor, when dry, a substance which rests on any non-conducting substance will be insulated, unless it communicates with the ground, the floor, a table, &c.

386. When a communication is made between a conductor and an excited surface, (*See No.* 382,) the electricity from the excited surface is immediately conveyed by the conductor to the ground;* but if the conductor be insulated, its whole surface will become electric, and it is said to be charged.

387. The principal mode of exciting electricity is by friction.

Thus, if a thick cylinder of sealing-wax, or sulphur, or a glass tube† be rubbed with a silk handkerchief, a piece of clean flannel, or the fur of a quadruped, the electric fluid will be excited and may be communicated to other substances from the electric thus excited. The electricity excited in glass is called the *vitreous* or *positive* electricity; and that obtained from sealing wax, or other resinous substances, is called *resinous* or *negative* electricity.

388. The vitreous and resinous, or, in other words, the positive and negative electricities always accompa-

* The earth may be considered as the principal reservoir of electricity; and when a communication exists, by means of any conducting substance, between a body containing more than its natural share of the fluid, and the earth, the body will immediately lose its redundant quantity, and the fluid will escape to the earth. Thus, when a person holds a metallic tube to an excited surface, the electricity escapes from the surface to the tube, and passes from the tube through the person (as living animals are good conductors) to the floor; and the floor being connected with the earth by conducting substances, such as the timbers, &c which support the building, the electricity will finally pass off by a regular succession of conducting substances from the excited surface to the earth. But if the chain of conducting substances be interrupted—that is, if any non-conducting substance occurs between the excited surface and the course which the fluid takes in its progress to the earth, the conducting substances will be insulated, and become charged with electricity. Thus, if an excited surface be connected by a long chain to a metallic tube, and the metallic tube be held by a person who is standing on a stool with glass legs, or on a cake of sealing-wax, resin, or any other non-conducting substance, the electricity cannot pass to the ground, and the person, the chain and the tube will all become electrified.

† Whatever substance is used, it must be perfectly dry. If, therefore, a glass tube be used, it should previously be held to the fire, and gently warmed, in order to remove all moisture from its surface.

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386. When a communication is made between a conductor and an excited surface, where is the electricity from the excited substance conveyed? When is it said to be charged? When a communication exists by means of any conducting substance, between a body containing more than its natural share of the fluid and the earth, what will become of the redundant quantity which the body possesses? What illustration of this is given? What follows if this chain of conducting substances be interrupted? 387. What is the principal mode of exciting electricity? What illustration of this is given? What is the electricity excited in glass called? What is that obtained from resinous substances called? 388. What is stated in No. 388 with regard to positive and negative electricity?

ny each other; for if any surface become positive, the surface with which it is rubbed will become negative; and if any surface be made positive, the *nearest* conducting surface will become negative. And if positive electricity be communicated to one side of an *electric*, (as a pane of glass, or a glass phial,) the opposite side will become negatively electrified, and the plate or the glass is then said to be charged.

When one side of a metallic, or other conductor, receives the electric fluid, its whole surface is instantly pervaded; but when an electric is presented to an electrified body, it becomes electrified in a small spot only.

When two surfaces oppositely electrified are united, their powers are destroyed; and if their union be made through the human body, it produces an affection of the nerves, called an electric shock.

Bodies that are charged with the same kind of electricity, appear to repel each other; but if one have more and the other less than its share, they will first attract one another, until the equilibrium is restored, and then repel each other.

389. The Leyden jar is a glass vessel used for the purpose of accumulating the electric fluid, procured from excited surfaces.

Fig. 117.

Fig. 117 represents a Leyden jar. It is a glass vessel or phial coated both on the inside and the outside with tin foil. It is provided with a cork or wooden stopper through which a metallic rod passes, terminating in a brass knob or ball at the top, and connected by means of a wire, at the other end, with the inside coating of the jar. The coating extends both on the inside and outside only to within two or three inches of the top, or the stopper. Thus prepared, when an excited surface is applied to the brass knob, or connected with it by means of a chain or any conducting surface, it parts with its electricity, and the fluid enters the jar, which is then said to be charged.

When the Leyden jar is charged, the fluid is contained in the inside coating of the phial; and as this coating is insulated, the fluid will remain in the jar until a communication is made by means of some conducting substance, between the inside and the outside of t e jar. If then a person apply one hand or finger to the brass knob, and the other to the outside coating of the jar, a

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What follows when one side of a metallic, or other conductor, receives the electric fluid? What follows when an electric is presented to an electrified body? What follows when two surfaces, oppositely electrified, are united? When do electric bodies repel each other? When do they attract each other? 389. For what is the Leyden jar used? What does fig. 117 represent? What is a Leyden jar? When is the jar said to be charged? How can the jar be discharged?

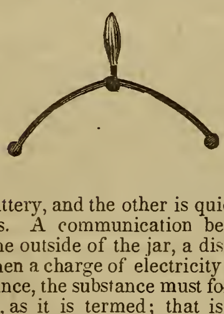
communication will be formed by means of the brass knob with the inside and outside of the jar, and the jar will be discharged. A phial or jar that is insulated cannot be charged.

390. An electrical battery is composed of a number of Leyden jars connected together. The inner coatings of the jars are connected together by chains or metallic bars attached to the brass knobs of each jar ; and the outer coatings have a similar connexion established by placing the phials on a sheet of tin foil. The whole battery may then be charged like a single phial, or jar. For the sake of convenience in discharging the battery, a knob, connected with the tin foil on which the jars stand, projects from the bottom of the box which contains the jars.

391. The *jointed* discharger is an instrument used to discharge a jar, or battery.

Illustration. Fig. 118 represents the jointed discharger. It consists of two rods, generally of brass, terminating at one end in brass balls, and connected together at the other end by a joint, like that of a pair of tongs, allowing them to be opened or closed. It is furnished with a glass handle, to secure the person who holds it from the effects of a shock. When opened, one of the balls is made to touch the outside coating of the jar, or the knob connected with the bottom of the battery, and the other is quickly applied to the knob of the jar, or jars. A communication being thus formed, between the inside and the outside of the jar, a discharge of the fluid will be produced.

Fig. 118.



When a charge of electricity is to be sent through any particular substance, the substance must form a part of the *circuit of the electricity*, as it is termed; that is, it must be placed in such a manner that the fluid cannot pass from the inside to the outside surface of the jar, or battery, without passing through the substance in its passage.

If the balls be removed from the jointed discharger, and the two rods terminate in sharp points, the electricity will pass off silently and produce but little effect.

Can an insulated jar be charged? 390. Of what is an electrical battery composed? How are the inner coatings of the jars connected together? How are the outer coatings connected? In what way is the battery charged. 391. What is the jointed discharger? What does fig. 118 represent? Of what does it consist? What is necessary when a charge of electricity is to be sent through any particular substance? How can the electricity be made to pass off silently?

392. Metallic rods, with sharp points, silently attract the electric fluid.

A Leyden jar, or a battery, may be silently discharged by holding the finest needle in the hand towards the knob. It is on this principle that lightning-rods are constructed. The electric fluid is silently drawn from the cloud by the sharp points on the rods, and is thus prevented from suddenly exploding on high buildings.

Electricity, of one kind or the other, is generally *induced* in surrounding bodies by the *vicinity* of a highly-excited electric. This mode of communicating electricity *by approach*, is styled *induction.*

Any body, capable of free motion, on approaching another body, powerfully electrified, will be thrown into a contrary state of electricity. Thus, a feather, brought near to a *glass tube* excited by friction, is attracted by it; and, therefore, previously to its touching the tube, negative electricity must have been induced in it. On the contrary, if a feather be brought near to excited *sealing-wax*, it will be attracted, and, consequently, positive electricity must have been induced in it before contact.

When electricity is communicated from one body to another *in contact* with it, it is called electricity *by transfer.*

393. The electrical machine is a machine constructed for the purpose of accumulating or collecting electricity, and transferring it to other substances.

Electrical machines are made in various forms, but all on the same principle, namely, the attraction of metallic points. The electricity is excited by the friction of silk on a glass surface, assisted by a mixture or preparation called an amalgam.* The glass surface is made either in the form of a cylinder or a circular plate, and the machine itself is called a cylinder or a plate machine, according as it is made, with a cylinder or a plate.†

* The amalgam is composed of mercury, tin and zinc. That recommended by Singer, is made by melting together one ounce of tin and two ounces of zinc, which are to be mixed, while fluid, with six ounces of mercury, and agitated in an iron, or thick wooden box, until cold. It is then to be reduced to a very fine powder in a mortar, and mixed with a sufficient quantity of lard to form it into a paste.

† The electrical machine described in fig. 119 is a plate machine, and an exact representation of the one belonging to the "*Boston School Set.*" For one of its size, it is a machine of very great power, and, together with the other implements belonging to the same set, was constructed by Messrs. A. & D. Davis, of this city. It is entirely insulated, so that either positive or negative electricity may be obtained from it.

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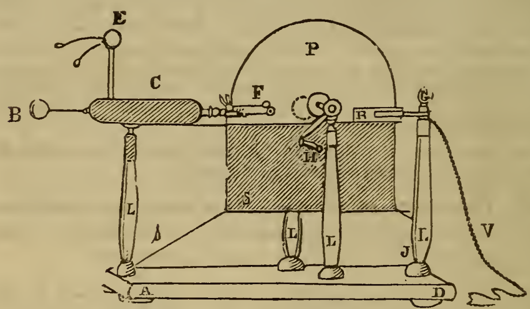
392. In what way do metallic rods, with sharp points, attract the electric fluid? Upon what principle are lightning-rods constructed? When is electricity said to be communicated by induction? When, by transfer? 393. For what purpose is the electrical machine constructed? Upon what principle are all electrical machines constructed? How is the electricity excited? Of what is the amalgam composed? In what form is the glass surface made? When is the machine called a plate machine? When is it called a cylinder machine?

Fig. 119 represents a plate electrical machine. A D is the stand of the machine, L L L L are the four glass legs, or posts which support and insulate the parts of the machine. P is the glass plate, (which in some machines is a hollow cylinder,) from which the electricity is excited, and H is the handle by which the plate (or cylinder) is turned. R is a leather cushion, or rubber, held closely to both sides of the glass plate by a brass clasp, supported by the post G L, which is called the rubber post. S is a silk bag,* embraced by the same clasp that holds the leather cushion or rubber; and it is connected by strings S S S attached to its three other corners,

Fig. 119.



to the legs L L and the fork F of the prime conductor. C is the prime conductor, terminating at one end with a moveable brass ball, B, and at the other by the fork F, which has one prong on each side of the glass plate. On each prong of the fork there are several sharp points projecting towards the plate, to collect the electricity (*See No.* 392,) as it is generated by the friction of the plate against the rubber. V is a chain or wire attached to the brass ball on the rubber post, and resting on the table or the floor, designed to convey the fluid from the ground to the plate. When negative electricity is to be obtained, this chain is removed from the rubber post, and attached to the prime conductor, and the electricity is to be gathered from the ball on the rubber post.

The operation of the machine is as follows: By turning the handle H the glass plate is pressed by the rubber. The friction of the rubber against the glass plate (or cylinder) produces a transfer of the electric fluid from the rubber to the plate; that is, the cushion becomes negatively and the glass positively electrified. The fluid which thus adheres to the glass, is carried round by the revolution of the cylinder; and its escape being prevented by the silk bag, or flap, which covers the plate (or cylinder) until it comes to the im-

* In cylindrical machines this silk bag is called "*the flap.*"

What does figure 119 represent? Explain the figure. Explain the operation of the machine.

mediate vicinity of the metallic points, on the fork F, it is attracted by the points, and carried by them to the prime conductor. Positive electricity is thus accumulated in the prime conductor, while the conductor on the rubber post, being deprived of this electricity, is negatively electrified. The fluid may then be collected by a Leyden jar, from the prime conductor, or conveyed, by means of a chain attached to the prime conductor, to any substance which is to be electrified. If both of the conductors are insulated, but a small portion of the electric fluid can be excited; for this reason, the chain *must in all cases be attached to the rubber post, when positive electricity is required, and to the prime conductor, when negative electricity is wanted.*

Experiments with the Electrical Machine.

1. On the prime conductor of the electrical machine is placed the electrometer,* E. It consists of a wooden ball mounted on a metallic stick, or wire, having two pith balls, suspended by silk or hair. When the machine is worked, the pith balls, being repelled, fly apart, as is represented in the figure; and they will continue elevated until the electricity is drawn off. But if an uninsulated conducting substance touch the prime conductor, the pith balls will fall. The height to which the balls rise, and the quickness with which they are elevated, afford some test of the quality of the machine.

2. The balls of the electrometer, when elevated, are attracted by an excited piece of sealing-wax or resin, and repelled by a piece of excited glass. [*See No.* 382.]

3. If an electric, or a non-conductor, be presented to the prime conductor, when charged, it will produce no effect on the balls; but if a non-electric, or any conducting substance be presented to the conductor, the balls of the electrometer will fall. This shows that the conductor has parted with its electricity, and that the fluid has passed off to the earth through the substance, and the hand of the person presenting it.

4. When the machine is turned, if a person touches the prime conductor, the fluid passes off through the person to the floor without his feeling it. But if he present his finger, his knuckle, or any part of the body, *near* to the conductor, without touching it, a spark will pass from the conductor to the knuckle, which will produce a sensation similar to the pricking of a pin or needle.

5. If a person stand on a stool with glass legs, or any other non-conductor, he will be *insulated.* If in this situation he touches the

* The word "*electrometer*" means "*a measurer of electricity.*" It is made in a variety of forms. It sometimes consists of a single pith ball, attached to a light rod, in the manner of a pendulum, before a graduated arc or circle. An *electroscope* is an instrument of more delicate construction, to detect the presence of electricity.

To what must the chain be attached when positive electricity is required? To what must it be attached when negative electricity is wanted? 1. What is the first experiment, mentioned, with the electrical machine? What does the word electrometer mean? Of what does it sometimes consist? What is an electroscope? 2. What is the second experiment? 3. What is the third? What does this show? 4. What is the fourth? 5. What is the fifth?

prime conductor, or a chain connected with it, when the machine is worked, sparks may be drawn from any part of the body in the same manner as from the prime conductor. While the person remains insulated, he experiences no sensation from being filled with electricity; or, if a metallic point be presented to any part of his body, the fluid may be drawn off silently, without being perceived. But if he touch a blunt piece of metal, or any other conducting substance, or if he steps from the stool to the floor, he will feel the electric shock; and the shock will vary in force according to the quantity of fluid with which he is charged.

6. The Leyden jar may be charged by presenting it to the prime conductor, when the machine is worked. If the ball of the jar touch the prime conductor, it will receive the fluid silently; but if the ball of the jar be held at a small distance from the prime conductor, the sparks will be seen darting from the prime conductor to the jar with considerable noise.

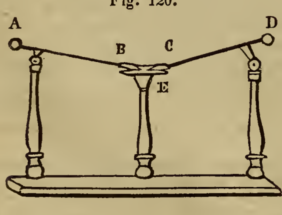
The jar may in like manner be filled with negative electricity, by applying it to the ball on the rubber part, and connecting the chain with the prime conductor.

7. If the Leyden jar is charged from the prime conductor, (that is, with positive electricity) and presented to the pith balls of the electrometer, they will be repelled; but if the jar is charged from the brass ball of the rubber post, (that is, with negative electricity) they will be attracted.

8. If the electrometer be removed from the prime conductor, and a pointed wire be substituted for it, a wire with sharp points bent in the form of an S, resting upon it, will be made to revolve rapidly. In a similar manner the motion of the sun and the earth around their common centre of gravity, together with the motion of the earth and the moon may be represented.*

9. If powdered resin be scattered over dry cotton wool, loosely wrapped on one end of the jointed discharger, it may be inflamed by the discharge of the battery or a Leyden jar. Gunpowder may be substituted for the resin.

Fig. 120.



10. The *universal discharger*, represented in figure 120, is an instrument for directing a charge of electricity through any substance, with certainty and precision. It consists of two sliding rods, A B and C D, terminating at the extremities, A and D, with brass balls, and at the other ends, which rest upon the ivory table or stand E,

*In the electrical department of the "*Boston School Set*," there is a brass wire in the form of an S, as above described, together with brass balls, mounted on wires, to represent the sun, earth, and moon, revolving around their common centre of gravity.

6. What is the sixth? How may the jar be filled with negative electricity? 7. What is the seventh? 8. What is the eighth? 9. What is the ninth? 10. What figure represents the universal discharger? What is its use? Of what does it consist?

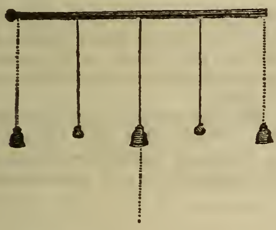
having a fork, to which any small substance may be attached. The whole is insulated by glass legs or pillars. The rods slide through collars, by which means their distance from one another may be adjusted.

In using the universal discharger, one of the rods or slides must be connected by a chain, or, otherwise, with the outside, and the other with the inside coating of the jar or battery. By this means the substance through which the charge is to be sent is placed within the electric circuit. (*See No.* 391, *Illustration.*)

By means of the universal discharger, a piece of a watch-spring, or any other small metallic substance, may be burnt. The substance must be placed in the forks of the slides, and the slides placed within the electric circuit, in the manner described in the last paragraph. In the same manner, by bringing the forks of the slides into contact with a substance placed upon the ivory stand of the discharger, such as an egg, a piece of a potato, water, &c. it may be illuminated.

11. The electrical bells, represented in figure 121, are designed to show the effects of electrical attraction and repulsion. They are thus to be applied. The ball B of the prime conductor, with its rod, is to be unscrewed, and the rod on which the bells are suspended is to be screwed in its place. The middle bell is to be connected by a chain, with the table or the floor. When the machine is then slowly turned, the balls suspended between the bells will be alternately attracted and repelled by the bells, and cause a constant ringing. If the battery be charged and connected with the prime conductor, the bells will continue to ring until all the fluid from the battery has escaped.

Fig. 121.



It may be observed that the fluid from the prime conductor passes readily from the two outer bells, which are suspended by chains; they, therefore, attract the two balls towards them. The balls becoming electrified by contact with the outer bells, are repelled by them and driven to the middle bell, to which they communicate their electricity; having parted with their electricity they are repelled by the middle bell, and again attracted by the outer ones, and thus the constant ringing is maintained. The fluid which is communicated to the middle bell, is conducted to the earth by the chain attached to it.

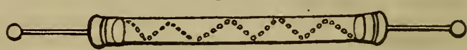
12. Ether, or spirits of wine, may be inflamed by a spark communicated from a person, in the following manner. The person standing on the insulating stool, (that is, the stool with glass legs,)

What is necessary in using the universal discharger? What is effected by this means? What experiments are shown by means of the universal discharger? How must the substance be placed? 11. What fig. represents the electrical bells? What are they designed to show? How are they to be applied? What farther may be observed with regard to this last experiment? 12. What is the twelfth experiment mentioned?

receives the electric fluid from the prime conductor, by touching the conductor or any conducting substance in contact with it, he then inserts the knuckles of his hand in a small quantity of sulphuric ether, or spirits of wine, held in a shallow metallic cup, by another person, who is not insulated, and the ether or spirits immediately inflames. In this case the fluid passes from the conductor to the person who is insulated, and he becomes charged with electricity. As soon as he touches the liquid in the cup, the electric fluid, passing from him to the spirit, sets it on fire.

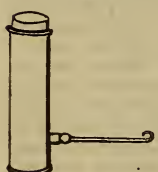
13. The passage of the electric fluid from one conducting substance to another, is beautifully exhibited by means of a glass tube having a brass ball at each end, and coated in the inside with small pieces of tin foil, placed at small distances from each other in a spiral direction, as represented in figure 122. This is called the spiral tube.

Fig. 122.



In the same manner various figures, letters, and words may be represented, by arranging similar pieces of tin foil between two pieces of flat glass. These experiments appear more brilliant in a darkened room.

Fig. 123.



14. Fig. 123 represents the hydrogen cannon or pistol. When filled with hydrogen gas,* if the insulated knob K be presented to the prime conductor, it will immediately explode.

Fig. 124.

* Connected with "*the Boston School Set*" of philosophical apparatus, is an article called by the manufacturer "a gasometer," but which is more properly a gas generator. It is represented in Fig. 124. It consists of a glass vessel, with a brass cover, on the centre of which is a stop cock; from the inside of the cover, another glass vessel is suspended with its open end downwards. Within this, a large piece of zinc is suspended by a wire. The outer vessel contains a mixture of sulphuric acid and water, about nine parts of water to one of acid. When the cover, to which the inner glass is firmly fixed, is placed upon the vessel, the acid acting upon the zinc, causes the metal to absorb the oxygen of the water, and the hydrogen, the other constituent part of the water (*See Illustration* 1, *under No.* 38., page 12.) being thus disengaged, rises in the inner glass, from which it expels the water; and when the stop cock is turned the hydrogen gas may be collected in the hydrogen pistol, or any other vessel.

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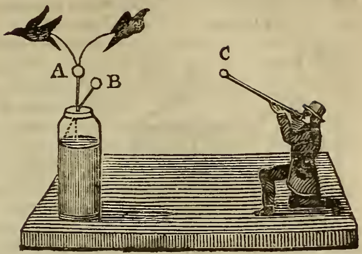
13. What is the thirteenth? What does fig. 122 represent? 14. What does fig. 123 represent? When will the pistol explode? What does fig. 124 represent? Of what does it consist?

Fig. 125.



15. Fig. 125 represents the electrical sportsman. From the larger ball of a Leyden jar two birds made of pith* are suspended by silk or hair. When the jar is charged the birds will rise, as represented in the figure, on account of the repulsion of the fluid in the jar. If the jar be then placed on the tin foil of the stand, and the smaller ball placed within a half inch of the end of the gun, a discharge will be produced, and the birds will fall.

16 If images, made of pith, or small pieces of paper, are placed under the insulated stool, (that is, the stool with glass legs,) and a connexion be made between the prime conductor and the top of the stool, the images, &c. will be alternately attracted and repelled; or, in other words, they will first rise to the electrified top of the stool, and thus becoming themselves electrified, by contact with the electrified top of the stool, they will then be repelled, and fall to the ground, the floor, or the table; where, parting with their electricity, they will again be attracted by the stool, thus rising and falling with considerable rapidity. In order to conduct this experiment successfully the images, &c. must be placed within a short distance of the bottom of the stool.

17. The straight receiver, connected with the pneumatic set, represented in figure 78, and described on page 86, as is there mentioned, is a jar coated with parallel strips of tin foil. Let this be charged, by placing the inside in contact with the prime conductor, and turning it round so that each strip may successively touch the ball of the conductor. If a number of pith balls be then placed within the glass, or the glass be placed over the pith balls, they will bound rapidly up and down, and their motions will be repeated, as often as the glass is touched by the hand, until the jar or glass has parted with its electricity. This experiment may also be performed by a plain glass tumbler.

18. A hole may be perforated through a quire of paper, by charging the battery, resting the paper upon the brass ball of the battery, and making a communication, by means of the jointed discharger, between the ball of one of the jars and the brass ball of the box. The paper, in this case, will be between the ball of the battery and the end of the discharger.

* This substance is produced in large quantities from the corn stalk, the whole of which, with the exception of the outside, is composed of *pith*.

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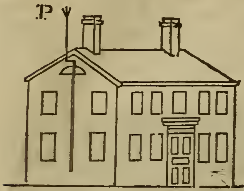
15. What does fig. 125 represent? When will the birds rise? Why will they rise? When will the birds fall? 16. What is the sixteenth experiment which is here mentioned? How must the images be placed to conduct the experiment successfully? 17. What is the seventeenth experiment? 18. What is the eighteenth experiment?

19. The thunder house, Fig. 126, is designed to show the security afforded by lightning rods, when lightning strikes a building. (*See No.* 392.) This is done by placing a highly combustible material in the inside of the house, and passing a charge of electricity through it. On the floor of the house is a surface of tin foil. The hydrogen pistol, (*See Fig.* 123.) being filled with hydrogen gas from the gasometer, (*See Fig.* 124,) must be placed on the floor of the thunder house, and connected with the wire on the opposite side. The house being then put together, a chain must be connected with the wire on the side opposite to the lightning rod, and placed in contact either with a single Leyden jar or with the battery. When the jar, thus situated, is charged, if a connexion be formed between the jar and the points of the lightning rod, the fluid will pass off silently, and produce no effect. But if a small brass ball be placed on the points of the rod, and a charge of electricity be sent to it, from the jar or the battery, the gas in the pistol will explode, and throw the parts of the house asunder with a loud noise.*

Fig. 126.



20. If the ball of the prime conductor be removed and a pointed wire be put in its place, the current of electricity flowing from the point, when the machine is turned, may be perceived by placing a lighted lamp before it; the flame will be blown *from* the point; and this will be the case in what part soever of the machine the point is placed, whether on the prime conductor or the rubber; or if the point be held in the hand and the flame placed between it and the machine, thus showing that in all cases the fluid is blown *from* the point. Delicate apparatus may be put in motion by the electric fluid when issuing from a point. In this way electrical orreries, mills, &c. are constructed. [*See No.* 9, *under Electrical Experiments.*]

* The success of this experiment depends upon the proper connexion of the jar with the lightning rod, and the electrical pistol. On the side of the house opposite to the lightning rod there is a wire, passing through the side, and terminating on the outside in a hook. When the house is put together, this wire, in the inside, must touch the tin foil on the floor of the house. The hydrogen pistol must stand on the tin foil, and its insulated knob or wire, projecting from its side, must be connected with the lower end of the lightning rod extending into the inside of the house. A communication must then be made between the hook on the outside of the house, and the outside of the jar or battery. This is conveniently done by attaching one end of a chain to the hook and holding the other end in the hand against the side of a charged jar. By presenting the knob of the jar to the points of the lightning rod no effect is produced, but if a brass ball be placed on the points at P, and the knob of the jar be presented to the ball, the explosion will take place. The thunder house belonging to "*the Boston School Set*" is held together by magnets attached to the inner surface of the sides.

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19. What does fig. 126 represent? What is it designed to show? How is this done? When will the fluids pass off silently and produce no effect? When will there be an explosion and the house be torn asunder? Upon what does the success of this experiment depend? What is said in the note with regard to the thunder house? 20. What is the twentieth experiment which is here mentioned? In what way are electrical orreries, mills, &c. constructed?

21. If the electrometer be removed from the prime conductor, and a tuft of feathers or hair, fastened to a stick or wire, be put in its place, on turning the machine the feathers or hair will become electrified, and the separate hairs will rise and repel each other. A toy is in this way constructed, representing a person under excessive fright. On touching the head with the hand, or any conducting substance, not insulated, the hair will fall.

22. Gold leaf may be forced into the pores of glass by placing it between two slips of window glass, pressing the slips of glass firmly together, and sending a shock from a battery through them.

23. If gold leaf be placed between two cards, and a strong charge be passed through them, it will be completely fused.

24. When electricity enters at a point, it appears in the form of a star; but when it goes out from a point, it puts on the appearance of a brush.

394. Lightning is the rapid motion of vast quantities of electric matter—and thunder is the noise produced by the rapid motion of lightning through the air.

395. The *aurora borealis*, (or northern lights,) is supposed to be caused by the electric fluid passing through highly rarified air; and most of the great convulsions of nature, such as earthquakes, whirlwinds, hurricanes, water-spouts, &c. are generally accompanied by electricity, and often depend upon it.*

*The experiments which have now been described exemplify all the elementary principles of the science of electricity. These experiments may be varied, multiplied and extended in innumerable forms, by an ingenious practical electrician. Among other things with which the subject may be made interesting, may be mentioned the following facts, &c.

A number of feathers, suspended by strings from an insulated conducting substance, will rise and present the appearance of a flight of birds. As soon as the substance is discharged the feathers will fall. The experiment described in No. 15. fig. 125, page 163, may be varied by placing the sportsman on the prime conductor, without the use of the Leyden jar, to which the birds are attached?

The experiment in No. 16 may be varied by the use of two plates of metal, one of which may be suspended from the prime conductor and the painted images placed between them.

Instead of the Leyden jar a plate of common glass, (a pane of window glass, for instance,) may be coated on both sides with tin foil, leaving the edges bare. A bent wire balanced on the edge of the glass, to the ends of which balls may be attached, with an image at each end, may be made to represent two persons tilting, on the same principle by which the electrical bells are made to ring. [*See No.* 11, *page* 161, *fig.* 121.]

A beautiful little saw mill was lately exhibited at a lecture at the Odeon, in this city, by Mr. Quimby, its ingenious contriver. The moving power was a wheel, with balls at the ends of the spokes, situated within the attractive influence of two larger balls, differently electrified. As the balls on the spokes were attracted by one of the larger balls, they changed their electrical state and were attracted by the other, which, in its return, repelled them, and thus the motion

21. What is the twenty-first experiment? 22. What is the twenty-second? 23. What is the twenty-third? 24. What is the twenty-fourth? 394. What is lightning? What is thunder? 395. How is the aurora borealis supposed to be caused?

The electricity which a body manifests by being brought near to an excited body, without receiving a spark from it, is said to be acquired by *induction*. When an insulated but unelectrified conductor is brought near an insulated charged conductor, the end near to the excited conductor assumes a state of opposite electricity, while the

being given to the wheel was communicated by cranks at the end of the axle to the saws above.

When the hand is presented to the prime conductor, a spark is communicated, attended with a slightly painful sensation. But if a pin or a needle be held in the hand with the point towards the conductor, neither spark nor pain will be perceived, owing to the attracting, (or perhaps, more properly speaking, the *receiving*) *power*, of the point.

That square rods are better than round ones to conduct electricity silently to the ground and thus to protect buildings, may be proved by causing each kind of rod to approach the prime conductor when charged. It will thus be perceived that while little effect is produced on the pith balls of the electrometer by the near approach of the round rod, on the approach of the square one the balls will immediately fall. The round rod also, will produce an explosion and a spark, from the ball of the prime conductor, while the square one will draw off the fluid silently.

The effects of pointed conductors upon clouds charged with electricity may be familiarly exemplied by suspending a small fleece of cotton wool from the prime conductor, and other smaller fleeces from the upper one, by small filaments. On presenting a point to them they will be repelled and all drawn together; but if a blunt conductor approach them they will be attracted.

From a great variety of facts, it has been ascertained that lightning rods afford but little security to any part of a building beyond twenty feet from them; and that when a rod is *painted* it loses its conducting power. The lightning rods of the most approved construction, and in strictest accordance with philosophical principles, are composed of *small* square rods, (similar to nail rods.) They run over the building, and down each of the corners, presenting many elevated points in their course. At each of the corners, and on the chimneys, the rods are elevated several feet above the building. Rods of this description have been erected on all the public school houses and other public buildings of this city, by order of the city authorities. They were constructed by Dr. King. Mr. Quimby, of Charlestown, has introduced an improvement on the rods of Dr. King by twisting the square rods, and thus multiplying the sharp surfaces presented to collect the fluids.

The removal of silk and woollen garments, worn during the day in cold weather is often accompanied by a slight noise resembling that of sparks issuing from a fire. A similar effect is produced on passing the hand softly over the back of a cat. These effects are produced by electricity.

It may here be remarked that the terms positive and negative are merely relative terms as applied to the subject of electricity. Thus, a body which is possessed of its natural share of electricity is positive in respect to one that has less, and negative in respect to one that has more than its natural share of the fluid. So, also, one that has more than its natural share is positive with regard to one that has only its natural share, or less than its natural share—and negative in respect to one having a larger share than itself.

The experiments with the spiral tube, page 162, may be beautifully varied by having a collection of such tubes placed on a stand; and a jar coated with small strips resembling a brick wall, presents, when it is charged, a beautiful appearance in the dark.

The electric fluid occupies no perceptible space of time in its passage through its circuit. It always seems to prefer the shortest passage, when the conductors are equally good. Thus, if two, ten, a hundred, or a thousand or more persons, join

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Why are square rods better than round ones to conduct electricity silently to the ground, and thus protect buildings from lightning? How far beyond the rod do lightning rods afford protection? In what way are the most approved lightning rods constructed? What is remarked with regard to the terms negative and positive? How can this be illustrated? What is said with regard to the time the electric fluid occupies in its passage through its circuit? By what is the electricity which a body manifests by being brought near to an excited body without receiving a spark from it, said to be acquired? When an insulated, but unelectrified conductor, is brought near an insulated charged conductor, what is said with regard to the end near the excited conductor?

farther end assumes the same kind of electricity—that is, if the conductor is electrified positively, the unelectrified conductor will be negative at the nearer end and positive at the further end, while the middle point evinces neither positive nor negative electricity.

hands and be made part of the circuit of the fluid in passing from the inside to the outside of a Leyden jar, they will all feel the shock at the same moment of time. But, in its passage, the fluid always prefers the best conductors. Thus, if two clouds, differently electrified, approach one another, the fluid, in its passage from one cloud to the other, will sometimes take the earth in its course, because the air is a bad conductor.

In thunder storms, the electric fluid sometimes passes from the clouds to the earth, and sometimes from the earth to the clouds; and sometimes, as has just been stated, from one cloud to the earth, and from the earth to another cloud.

It is not safe, during a thunderstorm, to take shelter under a tree, because the tree attracts the fluid, and the human body being a better conductor than the tree, the fluid will leave the tree and pass into the body.

It is equally dangerous to hold in the hand edge tools, or any sharp point which will attract the fluid. Carpenters have lost their lives during a thunder storm by carrying edge tools. An instance of this kind occurred in this city about ten years ago. A carpenter imprudently went to the window of a house, where he was at work, during a thunder storm, with a chisel in his hand. The sharp edge of the tool attracted the fluid and he was instantly killed.

The safest position that can be chosen during a thunder storm is a recumbent posture on a feather bed; and in all situations a recumbent is safer than an erect position. No danger is to be apprehended from lightning when the interval between the flash and the noise of the explosion is as much as three or four seconds. This space of time may be conveniently measured by the beatings of the pulse, if no time piece is at hand.

Lightning rods were first proposed by Dr. Franklin, to whom is also ascribed the honor of the discovery that thunder and lightning are the effects of electricity. He raised a kite, constructed of a silk handkerchief adjusted to two light strips of cedar, with a pointed wire fixed to it; and fastening the end of the twine to a key, and the key, by means of a piece of silk lace, to a post, (the silk lace serving to insulate the whole apparatus,) on the approach of a thunder cloud, he was able to collect sparks from the key, to charge Leyden jars, and to set fire to spirits. This experiment established the identity of lightning and electricity. The experiment was a dangerous one, as was proved in the case of Professor Richman, of St. Petersburgh, who fell a sacrifice to his zeal for electrical science, by a stroke of lightning from his apparatus.

Among the most remarkable facts, connected with the science of Electricity, may be mentioned the power possessed by certain species of fishes of giving shocks, similar to those produced by the Leyden jar. There are three animals possessed of this power, namely, the Torpedo, the Gymnotus Electricus, (or Surinam Eel,) and the Silurus Electricus. But although it has been ascertained that the Torpedo is capable of giving shocks to the animal system, similar to those of the Leyden jar, yet he has never been made to afford a spark, nor to produce the least effect upon the most delicate electrometer. The Gymnotus gives a small but perceptible spark. The electrical powers of the Silurus are inferor to those of the torpedo or the gymnotus, but still sufficient to give a distinct shock to the human system. This power seems to have been bestowed upon these animals to enable them to secure their prey; and to resist the attacks of their enemies. Small fishes, when put into the water where the gymnotus is kept, are generally killed or stunned by the shock and swallowed by the animal, when he is hungry. The gymnotus seems to be possessed of a new kind of sense, by which he perceives whether the bodies presented to him are conductors or not.

What example is given to illustrate this? What example is given to show that the fluid prefers the best conductors? In what different ways does the electric fluid sometimes pass in thunder storms? Why is it unsafe, during a thunder storm, to take shelter under a tree, or to hold in the hand any edge tools? What position is the safest in a thunder storm? When is there no danger to be apprehended from the lightning? By whom were lightning rods first proposed? Who first discovered that thunder and lightning are the effects of electricity? In what way did he prove this? What is related as among the most remarkable facts connected with the science of electricity?

SECTION XVII.

Galvanism, or Voltaic Electricity.

396. Galvanism is a branch of Electricity, which derives its name from Galvani,* who first discovered it. Electricity is produced by the mechanical action of bodies on one another; but Galvanism, or Galvanic Electricity is produced by their chemical action.

397. The motion of the electric fluid excited by galvanic power, differs from that explained in the science of electricity, in its duration; for while the latter exhibits itself in sudden and intermitted shocks and explosions, the former continues in constant and uninterrupted action.

398. The nerves and muscles of animals are most easily affected by the galvanic fluid; but the voltaic or galvanic battery possesses the most surprising powers of chemical decomposition.

399. The galvanic fluid or influence is excited by the contact of pieces of different metal, and sometimes by different pieces of the same metal.

Illustration first. If a living frog, or a fish, (as a flounder,) having a slip of tin foil pasted on its back, be placed upon a piece

* Dr. Aloysius Galvani was a Professor of Anatomy in Bologna, and made his discoveries about the year 1790. His wife, being consumptive, was advised to take, as a nutritive article of diet, some soup made of the flesh of frogs. Several of these animals, recently skinned for that purpose, were lying on a table in his laboratory, near an electrical machine, with which a pupil of the professor was amusing himself, in trying experiments. While the machine was in action he chanced to touch the bare nerve of the leg of one of the frogs, with the blade of a knife that he held in his hand, when suddenly the whole limb was thrown into violent convulsions. Galvani being informed of the fact, repeated the experiment, and examined minutely all the circumstances connected with it. In this way he was led to the discovery of the principles which form the basis of this science. The science was subsequently extended by the discoveries of Professor Volta, of Pavia, who first constructed the Galvanic, or Voltaic Pile, in the beginning of the present century.

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396. What is galvanism? How is electricity generally produced? By whom and when was galvanism discovered? What led to the discovery? 397. How does the motion of the electric fluid, excited by galvanic power, differ from that explained in the science of electricity? 398. What bodies are most easily affected by the galvanic fluid? 399. How is the galvanic fluid or influence excited? What illustrations of this are given?

of zinc, spasms of the muscles will be excited whenever a communication is made between the zinc and the tin foil.

Illustration second. If a person place a piece of one metal, as a half dollar, above his tongue, and a piece of some other metal, as zinc, below the tongue, he will perceive a peculiar taste; and, in the dark, will see a flash of light, whenever the outer edges of the metals are in contact.

Illustration third. A faint flash may be made to appear before the eyes by putting a slip of tin foil upon the bulb of one of the eyes, a piece of silver in the mouth, and making a communication between them. In these experiments, no effect is produced so long as the metals are kept apart; but on bringing them into contact, the effects above described are produced.

400. The conductors of the galvanic fluid are divided into the *perfect* and the *imperfect.* Metallic substances, plumbago and charcoal, the mineral acids and saline solutions are *perfect* conductors. Water, oxydated fluids, as the acids and all the substances that contain these fluids, alcohol, ether, sulphur, oils, resins, and metallic oxides, are *imperfect* conductors.

401. To produce any galvanic action it is necessary to form what is called a galvanic circle; that is, a certain order or succession of substances capable of producing the fluid.

402. To produce electricity in the common way (*as has been stated under the head of electricity,*) it is necessary to excite an electric or non-conducting substance. But to produce the galvanic fluid, all that is necessary is the simple *contact* of different conducting substances with each other.

403. The simplest galvanic circle is composed of three conductors, one of which must be solid, the other fluid; the third may be either solid or fluid.

404. The process usually adopted for obtaining galvanic electricity is to place between two plates, of different kinds of metals, a fluid capable of exerting some chemical action on one of the plates while it has no action, or a different action, on the other, A communication is then formed between the two plates.

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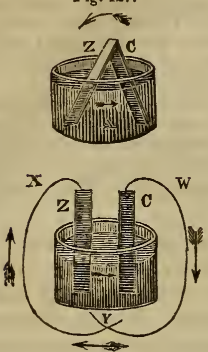
400. Into what are the conductors of the galvanic fluid divided? What substances are perfect conductors? What substances are imperfect conductors? 401. What is necessary in order to produce any galvanic action? 402. How does the manner of producing the galvanic fluid and electricity in the common way, differ? 403. Of what is the simplest galvanic circle composed? 404. What process is usually adopted for obtaining galvanic electricity?

Illustration. Fig. 127 represents a simple galvanic circle. It consists of a vessel containing a portion of diluted sulphuric acid, with a plate of zinc Z and of copper C immersed in it. The plates are separated at the bottom, and the circle is completed by uniting the plates at the top. The same effect will be produced, if, instead of allowing the metallic plates to come into direct contact, the communication between them be effected by wires extending from one to the other.

Fig. 127.



In the above arrangement, there are three elements or essential parts; * namely, the zinc, the copper, and the acid. The acid, acting chemically† upon the zinc, produces an alteration in the electrical state of the metal. The zinc communicating its natural share of the electrical fluid to the acid, becomes *negatively* ‡ electrified. The copper, attracting the same fluid from the acid, becomes *positively* electrified. Any conducting substance, therefore, placed within the line of communication between the positive and negative points, will receive the charge thus to be obtained. The arrows in fig. 127 show the direction of the current of positive electricity, namely, from the zinc to the fluid,—from the fluid to the copper,—from the copper back to the zinc. The substance to be submitted to the action of the fluid, must be placed in the line of communication between the copper and the zinc.

* It is essential in all cases to have three elements to produce galvanic action. In the experiments or illustrations under No. 399, the *moisture* of the animal, or of the mouth, supplies the place of the acid, so that the *three* constituent parts of the circle are completed.

† A certain quantity of electricity is always developed, or, in other words, converted from a latent to an active state, whenever a chemical action takes place between a fluid and a solid body. This is a general law of chemical action; and, indeed, it has been ascertained that there is so intimate a connexion between electrical and chemical charges, that the chemical action can proceed only to a certain extent, unless the electrical equilibrium, which has been disturbed, be again restored. Hence, we find that in the simple, as well as in the compound galvanic circle, the oxidation of the zinc proceeds with activity whenever the galvanic circle is completed; and that it ceases, or, at least, takes place very slowly, whenever the circuit is interrupted.

‡ It is a singular fact that in a simple galvanic circle, composed of zinc, acid and copper, the zinc end will always be negative, and the copper end positive; but in all *compound* galvanic circles, composed of the same elements, the zinc will be positive, and the copper *negative*.

Illustrate this by fig. 127. What effect will be produced if, instead of allowing the metallic plates to come into direct contact, the communication between them be effected by wires? How many parts are there in the above arrangement? What are they? What effect does the acid produce? What is the electrical state of the zinc? Of the copper? What singular fact is related in the note? What are the arrows, in fig. 127, designed to show? Where must the substance, to be submitted to the action of the fluid, be placed?

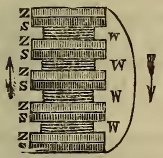
The electrical effects of a simple galvanic circle, such as has now been described, are, in general, too feeble to be perceived, except by very delicate tests. The muscles of animals, especially those of cold-blooded animals, such as frogs, &c., the tongue, the eye, and other sensitive parts of the body, being very easily affected, afford examples of the operation of simple galvanic circles. (*See Illustrations under No.* 399.) In these, although the quantity of electricity set in motion is exceedingly small, it is yet sufficient to produce very considerable effects; but it produces little or no effect on the most delicate electrometer.*

405. The galvanic effects of a simple circle may be increased, to any degree, by a repetition of the same simple combination. Such repetitions constitute compound galvanic circles, and are called galvanic piles or galvanic batteries, according to the mode in which they are constructed.

406. The voltaic pile consists of alternate plates of two different kinds of metal, separated by woollen cloth, card, or some similar substance.

Illustration. Fig. 128 represents a voltaic pile. A voltaic pile may be constructed in the following manner: Take a number, say twelve plates of silver, and the same number of zinc, and also of woollen cloth, the cloth having been soaked in a solution of sal ammoniac in water; with these a pile is to be formed in the following order: namely, a piece of silver, a piece of zinc, a piece of cloth, and thus repeated. These are to be supported by three glass rods, placed perpendicularly with pieces of wood at the top and bottom, and the pile will then be complete; and will afford a constant current of electric fluid through any conducting substance. Thus, if one hand be applied to the lower plate, and the other to the upper one, a shock will be felt, which will be repeated as often as the contact is renewed.

Fig. 128.



Instead of silver, copper plates, or plates of other metal, may be used in the above arrangement. The arrows in the figure, show the course of the current of electricity in the arrangement of silver, zinc, &c.

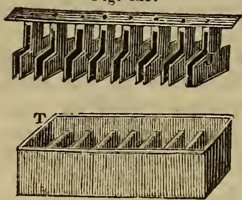
* On the principle of the simple galvanic circle, Dr. Hare, of Philadelphia, constructed a very powerful apparatus, which he called a *Calorimotor*, from its remarkable property of producing heat.

What is said of the electrical effects of a simple galvanic circle? What examples are given illustrating the operation of simple galvanic circles? Upon what principle is the calorimotor constructed? 405. How may the galvanic effects of the simple circle be increased? What are compound galvanic circles? 406. Of what does the voltaic pile consist? What does fig. 128 represent? How may a voltaic pile be constructed? Can any other metal be used? What are the arrows in the figure designed to show?

407. The voltaic battery is a combination of metallic plates, immersed by pairs in a fluid which exerts a chemical action on one of each pair of the plates, and no action, or, at least, a different action on the other.*

Illustration. Fig. 129 represents a Voltaic battery. It consists of a trough made of baked wood, wedgewood-ware, or some other non-conducting substance. It is divided into grooves or partitions, for the reception of the acid, or a saline solution, and the plates of zinc or copper (or other metals) are immersed by pairs in the grooves. These pairs of plates are united by a slip of metal passing from the one and soldered to the other; each pair being placed so as to enclose a partition between them, and each cell or groove in the trough containing a plate of zinc, connected with the copper plate of the succeeding cell, and a copper plate joined wth the zinc plate of the preceding cell. These pairs must commence with copper and terminate with zinc, or commence with zinc and terminate with copper. The communication between the first and last plates is made by wires, which thus complete the galvanic circuit. The substance to be submitted to galvanic action is placed between the points of the two wires.

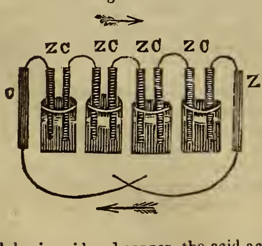
Fig. 129.



A compound battery of great power is obtained by uniting a number of these troughs. In a similar manner a battery may be produced by uniting several piles, making a metallic communication between the last plate of the one and the first plate of the next, and so on, taking care that the order of succession of the plates in the circuit be preserved inviolate.

The *Couronne des tasses*, represented in figure 130, is another form of the galvanic battery. It consists of a number of cups, bowls, or glasses, with the zinc and copper plates immersed in them, in the order represented in the figure; Z indicating the zinc, and C the copper plates; the arrows denoting the course of the electric fluid.

Fig. 130.



* The electricity excited by the battery, proceeds *from* the solid *to* the fluid which acts upon it chemically. Thus, in a battery composed of zinc, diluted sulphuric acid and copper, the acid acts upon the zinc, and not on the copper. The galvanic fluid proceeds, therefore, from the zinc to the acid, from the acid to the copper, &c.

407. What is the voltaic battery? What is said in the note with regard to the electricity excited by the battery? What does fig. 129 represent? Of what does the voltaic battery consist? How is the communication between the first and last plates made? Where must the substance which is to be submitted to galvanic action be placed? How can a compound battery of great power be obtained? What does fig. 130 represent? Of what does this battery consist?

The electric shock from the voltaic battery may be received by any number of persons, by joining hands, having previously wetted them.

The spark from a powerful voltaic battery acts upon and inflames gunpowder, charcoal, cotton, and other inflammable bodies, melts all metals, disperses diamonds, &c.

The wires, by which the circuit of the battery is completed, are generally covered with glass tubes, in order that they may be held, or directed to any substance.

408. There are three principal circumstances in which the electricity produced by the galvanic or voltaic battery, differs from that obtained by the ordinary electrical machine, namely,—

First. The very low degree of *intensity** of that produced by the galvanic battery, compared with that obtained by the machine.

Secondly. The very large quantity of electricity which is set in motion by the voltaic battery; and

Thirdly. The continuity of the current of voltaic electricity, and its perpetual reproduction, even while this current is tending to restore the equilibrium.†

* By *intensity* is here meant the same that is implied by density, as applied to matter. The *quantity* of electricity obtained by galvanic action is much greater than can be obtained by the machine; but it flows, as it were, in narrow streams. The action of the electrical machine may be compared to a mighty torrent, dashing and *exhausting itself* in one leap from a precipitous height. The galvanic action may be compared to a steady stream, supplied by an inexhaustible fountain. In other words, the *momentum* of the electricity excited by galvanism is less than that from the electrical machine—but the *quantity*, as has been stated, is greater.

† Whenever an electrical battery is charged, how great soever may be the quantity that it contains, the whole of the power is *at once* expended, as soon as the circuit is completed. Its action may be sufficiently energetic while it lasts, but it is exerted only for an instant, and like the destructive operation of lightning, can effect, during its momentary passage, only sudden and violent changes, which it is beyond human power to regulate or control. On the contrary, the voltaic battery continues for an indefinite time, to develop and supply vast quantities of electricity, which, far from being lost by returning to their source, circulate in a perpetual stream, and with undiminished force. The effects of this continued current on the bodies subjected to its action, will, therefore, be more definite, and will be constantly accumulating; and their amount, in process of time, will be incomparably greater than even those of the ordinary electrical explosion. It is, therefore, found that changes in the composition of bodies are effected by galvanism, which can be accomplished by no other means. The science of galvanism, therefore, has extended the field, and multiplied the means of investigation in the kindred sciences, especially that of chemistry.

How can the electric shock, from the voltaic battery, be received by any number of persons? What is said of the spark from a powerful voltaic battery? 408. In how many ways does the electricity produced by the galvanic or voltaic battery differ from that obtained by the ordinary electrical machine? What is the first? What is here meant by intensity? How does the quantity of electricity obtained by galvanic action, compare with that obtained by the machine? To what may the action of the electrical machine be compared? To what may the galvanic action be compared? What is the second way in which they differ? What is the third? What is said in the note with regard to the third circumstance in which the electricity obtained by the ordinary electrical machine differs from that produced by the galvanic battery? What is said of the effects of this continued current on the bodies subjected to its action?

A common electrical battery may be charged from a voltaic battery of sufficient size; but the largest calorimotor that has yet been constructed, furnishes no indication of attraction or repulsion equal to that which is given by the feeblest degree of excitation to a piece of sealing wax. A galvanic battery, consisting of fifty pairs of plates, will affect a delicate gold-leaf electrometer; and, with a series of one thousand pairs, even pith balls are made to diverge.

Voltaic piles have been constructed of layers of gold and silver paper. The effect of such piles remains undisturbed for years. With the assistance of two such piles, a kind of *perpetual motion*, or self-moving clock, has been invented by an Italian philosopher. The motion is produced by the attraction and repulsion of the piles exerted on a pith ball, on the principle of the electrical bells described on page 161, No. 11. The top of one of the piles was positive, and the bottom negative. The other pile was in an opposite state; namely, the top negative, and the bottom positive.

409. The effect of the voltaic pile on the animal body depends chiefly on the *number* of plates that are employed; but the intensity of the spark and its chemical agencies increase more with the *size* of the plates, than with their number.

410. Galvanism explains many facts in common life.

Porter, ale, or strong beer, is said to have a peculiar taste when drunk from a pewter vessel. The peculiarity of taste is caused by the galvanic circle formed by the pewter, the beer, &c., and the moisture of the under lip.

Silver is tarnished by the yolk of an egg. Here is another galvanic circle formed by the yolk, the silver, and the moisture of the tongue.

Works of metals, the parts of which are soldered together, soon tarnish in the places where the metals are joined.

Ancient coins, composed of a mixture of metal, have crumbled to pieces, while those composed of pure metal have been uninjured.

The nails and the copper in sheathing of ships are soon corroded about the place of contact. These are all the effects of galvanism.*

* The most striking effects of galvanism on the human frame, after death, were exhibited at Glasgow, a few years ago. The subject on which the experiments were made was the body of the murderer Clydesdale, who was hanged at that city. He had been suspended an hour, and the first experiment was made in about ten minutes after he was cut down. The galvanic battery employed consisted of 270 pairs of four inch plates. On the application of the battery to different parts of the body, every muscle was thrown into violent agitation; the leg was thrown out with great violence, breathing commenced, the face exhibited extraordinary grimaces, and the finger seemed to point out the spectators. Many persons were obliged to leave the room from terror or sickness; one gentleman fainted, and some thought that the body had really come to life.

Of what have voltaic piles been constructed? What has been produced with the assistance of two such piles? How and on what principle was the motion produced? 409. On what does the effect of the voltaic pile on the body depend? 410. What facts in common life does galvanism explain?

There are persons who profess to be able to find out seams in brass and copper vessels by the tongue, which the eye cannot discover; and, by the same means, to distinguish the base mixtures which abound in gold and silver trinkets.

SECTION XVIII.

Magnetism.

411. Magnetism treats of the properties and effects of the magnet, or loadstone.

412. There are two kinds of magnets, namely, the native or natural magnet, and the artificial.

413. The native magnet, or loadstone, is an ore of iron, found in iron mines, and has the property of attracting iron and other substances which contain it.

414. An artificial magnet is a piece of iron to which magnetic properties have been communicated.

For all purposes of accurate experiment, the artificial is to be preferred to the native magnet.

415. If a straight bar of hard tempered steel be held in a vertical position, (or, still better, in a position slightly inclined to the perpendicular, the lower end deviating to the north,) and struck several smart blows with a hammer, it will be found to have acquired, by this process, all the properties of a magnet; or, in other words, it will become an artificial magnet.

416. The properties of a magnet are four; namely, *First*, Polarity—*Second*, Attraction of unmagnetic iron —*Third*, Attraction *and repulsion* of *magnetic* iron—*Fourth*, The power of communicating magnetism to other iron.

417. By the *polarity* of a magnet is meant the property of pointing, or turning to the north and south poles.

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411. Of what does magnetism treat? 412. How many kinds of magnets are there? What are they? 413. What is the native magnet? What property does it possess? 414. What is an artificial magnet? Which magnet is preferred, for all purposes of accurate experiment? 415. How can an artificial magnet be made? 416. What is the first property of the magnet? Second? Third? Fourth? 417. What is meant by the polarity of a magnet?

The end which points to the north, is called the north pole of the magnet, and the other the south pole. The attractive power of a magnet is strongest at the poles.

When a magnet is supported in such a manner as to move freely, it will spontaneously assume a position directed *nearly* north and south. The end which points to the north, is called the north pole of the magnet; and that which points to the south, is called the south pole.

There are several ways of supporting a magnet, so as to enable it to manifest its polarity. *First*, by suspending it, accurately balanced, from a string. *Secondly*, by poising it on a sharp point. *Thirdly*, by fixing it on a piece of cork, and thus making it float on water.

418. A magnet, whether native or artificial, attracts iron or steel which has no magnetic properties; but it both *attracts* and *repels* those substances, when they are magnetic; that is, the north pole of one magnet will attract the south pole of another, and the south pole of one will attract the north of another; but the north pole of the one *repels* the north pole of the other, and the south pole of one repels the south pole of another. In few words, different poles attract, and similar poles repel each other.*

If either pole of a magnet be brought near any small piece of soft iron, it will attract it. Iron filings will also adhere in clusters to either pole.

If the north pole of a magnet, held in the hand, be presented to the same pole of a magnet balanced on a point, or suspended by a string, it will repel it—but it will attract the opposite pole.

419. A magnet may communicate its properties to other bodies. But these properties can be conveyed to no other substances than iron, nickel or cobalt.† All

* There is here a close analogy between the attractive and repulsive powers of the different kinds of electricity, (that is, the positive and the negative,) and the northern and southern polarities of the magnet. The same law obtains with regard to both; namely,—*between like powers there is repulsion; between unlike, there is attraction.*

† The accuracy of the above statement may, perhaps, be questioned, since Coulomb has discovered that "*all solid bodies are susceptible of magnetic influence.*" But the "*influence*" is perceptible only by the nicest tests, and under peculiar circumstances. [*See Electro-Magnetism.*]

Where is the attractive power of the magnet the strongest? When will a magnet assume a position directed nearly north or south? What is the north pole of the magnet? What is the south pole? In what ways can a magnet be supported so as to enable it to manifest its polarity. 418. What is said in No. 418 with regard to the attraction of magnets, whether native or artificial? What analogy is there between the attractive and repulsive powers of the different kinds of electricity, and the northern and southern polarities of the magnet? 419. Can a magnet communicate its properties to other bodies? To what substances, only, can these properties be conveyed?

natural and artificial magnets, as well as the bodies on which they act, are either iron in its pure state, or such compounds as contain it.

420. The powers of a magnet are increased by action, and are impaired and even lost by long disuse.

When the two poles of a magnet are brought together, so that the magnet resembles in shape a horse-shoe, it is called a horse-shoe magnet, and it may be made to sustain a considerable weight by suspending substances from a small iron bar, extending from one pole to the other. This bar is called the keeper. A small addition may be made to the weight every day.

421. Soft iron acquires the magnetic power very readily, and also loses it as readily—but hardened iron or steel acquires the property with difficulty, but when it has acquired it, retains it permanently.

422. When a magnet is broken or divided, each part becomes a perfect magnet, having both a north and south pole.

This is a remarkable circumstance, since the central part of a magnet appears to possess but little of the magnetic power—but when a magnet is divided *in the centre*, this very part assumes the magnetic power, and becomes possessed, in the one part, of the north, and in the other, of the south polarity.

423. The magnetic power of iron or steel resides wholly on the surface, and is independent of its mass.*

* In this respect there is a strong resemblance between magnetism and electricity. Electricity, as has already been stated, is wholly confined to the surface of bodies. In a few words, magnetism and electricity may be said to resemble each other in the following particulars.

1. Each consists of two species, namely, the vitreous and the resinous (or, the positive and negative) electricities; and the northern and southern (sometimes called the *Boreal*, and the *Austral*) polarity.

2. In both magnetism and electricity, those of the same name repel and those of different names attract each other [*See No.* 418.]

3. The laws of induction in both are similar.

4. The powers of attraction and repulsion in each vary inversely as the square of the distance. [*See No.* 74, *page* 20.]

5. The influence, in both cases, (as has just been stated,) resides at the *surface*, and is wholly independent of their *mass*.

But magnetism and electricity differ in the following particulars:

1. Electricity is capable of being excited in *all* bodies, and of being imparted

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Of what substance are all natural and artificial magnets, as well as the bodies on which they act, composed? 420. How can the powers of a magnet be increased? What is a horse-shoe magnet? How can it be made to sustain a considerable weight? What is this bar called? 421. How does soft iron differ from hardened iron, with respect to its acquiring and losing the magnetic power? 422. Does the breaking of a magnet cause any loss of its magnetic power? Why is this a remarkable circumstance? 423. Where does the magnetic power of iron or steel wholly reside? In what particulars do magnetism and electricity resemble each other? 1. What is the first? 2. What is the second? 3. What is the third? 4. What is the fourth? 5. What is the fifth? In what particulars do magnetism and electricity differ from each other? 1. What is the first?

424. Heat weakens, and a great degree of heat destroys the power of a magnet; but the magnetic attraction is not in the least diminished by the interposition of any bodies except iron, steel, &c.

Electricity frequently changes the poles of a magnet; and the explosion of a small quantity of gunpowder, on one of the poles, produces the same effect.

Electricity, also, sometimes renders iron and steel magnetic, which were not so before the charge was received.

425. The effects produced by two magnets, used together, are much more than double that of either one used alone.

426. When a magnet is suspended freely from its centre, the two poles will not lie in the same horizontal direction; one of them will incline towards the horizon, and the other will consequently rise; or, in other words, one end of the magnet will be *higher* than the other. This is called the inclination or *the dipping* of the magnet.

427. The magnet, when suspended, does not invariably point *exactly* to the north and south points, but varies a little towards the east or the west. This variation differs at different places, at different seasons, and at different times in the day.

428. The science of magnetism has rendered immense advantages to commerce and navigation, by

to all—Magnetism, with but few exceptions, resides in, and can be imparted only o iron, and its different compounds. [*See note to No.* 419.]

2. Electricity may be transferred from one body to another; in which case the body from which it is transferred loses the whole or a portion of its electricity. Magnetism cannot be transferred in the same manner; but it may be communicated from a magnet to another piece of iron or steel, in which case the magnet employed loses no part of its own power.

3. When an electrified body is divided near the middle, the two parts will possess the same kind of electricity which they had before the separation—but when a magnet is divided, or broken into any number of parts, each part will have both polarities, and become a perfect magnet.

4. The directive property, or the property of turning toward the north and south poles, belongs to the magnet alone.

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2. What is the second? 3. What is the third? 4. What is the fourth? 424. What effect has heat on the power of a magnet? By what is the magnetic attraction diminished? What effect has electricity on the poles of a magnet? What effect has electricity, sometimes, on iron and steel? 425. What proportion do the effects produced by two magnets, used together, bear to that of either used alone? 426. What is meant by the inclination or dipping of the magnet? 427. Does the magnet, when suspended, invariably point exactly to the north and south points? 428. What immense advantage has the science of magnetism rendered to commerce and navigation?

means of the mariners' compass.* The mariner's compass consists of a magnetised bar of steel, called *a needle;* having at its centre a cap fitted to it, which is supported on a sharp-pointed pivot fixed in the base of the instrument. A circular plate, or card, the circumference of which is divided into degrees, is attached to the needle, and turns with it. On an inner circle of the card the thirty-two points of the mariner's compass are inscribed.†

The needle is generally placed *under* the card of a mariner's compass, so that it is out of sight; but small needles, used on land, are placed above the card, and the card is permanently fixed to the box.

429. The north pole of a magnet is more powerful in the northern hemisphere, or north of the equator, and the south pole in the southern parts of the world.

430. When a piece of iron is brought sufficiently near to a magnet, it becomes itself a magnet; and bars of iron, that have stood long in a perpendicular situation, are generally found to be magnetical.

Artificial magnets are made by applying one or more powerful magnets to pieces of hard steel. The end which is touched by the north pole becomes the south pole of the new magnet, and that touched by the south pole, becomes the north pole. The magnet which is employed in magnetising a steel bar loses none of its power by being thus employed; and as the effect is

* The invention of the mariner's compass is usually ascribed to Flavio de Melfi, or Flavio Gioia, a Neapolitan, about the year 1302. Some authorities, however, assert that it was brought from China, by Marcus Paulus, a Venetian, in 1260. The invention is also claimed both by the French and English.

The value of this discovery may be estimated from the consideration, that, until then, mariners seldom trusted themselves out of sight of land; they were unable to make long or distant voyages, as they had no means to find their way back. This discovery enabled them to find a way where all is trackless—to conduct their vessels through the mighty ocean, out of the sight of land; and to prosecute those discoveries, and perform those gallant deeds which have immortalized the names of Cook, of La Perouse, Vancouver, Sir Francis Drake, Nelson, Parry, Franklin, and others.

† The compass is generally fitted by two sets of axes to an outer box, so that it always retains a horizontal position, even when the vessel rolls. When the artificial magnet or *needle* is kept thus freely suspended, so that it may turn North or South, the pilot, by looking at its position, can ascertain in what direction his vessel is proceeding; (*See No.* 417,) and, although the needle varies a little from a correct polarity, yet this variation is never so great, or so irregular, as seriously to impair its use as a guide to the vessel in its course over the pathless deep.

Of what does the mariner's compass consist? To whom is the invention of the mariner's compass usually ascribed? How may the value of this discovery be estimated? 429 Where are the north and south poles of a magnet the most powerful? 430. What effect has a magnet on a piece of iron, when it is brought sufficiently near to it? How are artificial magnets made? Does the magnet, which is employed in magnetising a steel bar, lose any of its power by being thus employed?

increased when two or more magnets are used, with one magnet a number of bars may be magnetised, and then combined together; by which means their power may be indefinitely increased. Such an apparatus is called a *magnetic magazine.**

A magnetic needle is made by fastening the steel on a piece of board and drawing magnets over it from the centre outwards.

A horse-shoe magnet should be kept *armed*, by a small piece of iron or steel, connecting the two poles.

Interesting experiments may be made by a magnet, even of no great power, with steel or iron filings, small needles, pieces of ferruginous substances, and black sand, which contains iron. Such substances may be made to assume a variety of amusing forms and positions, by moving the magnet *under* the card, paper, or table, on which they are placed. Toys, representing fishes, frogs, &c., which are made to appear to bite at a hook, birds, floating on the water, &c. are constructed on magnetic principles, and sold in the shops.

SECTION XIX.

Electro-Magnetism.

431. Electro-Magnetism treats of the combined powers of electricity and magnetism.

* There are many methods of making artificial magnets. One of the most simple and effectual consists in passing a strong horse-shoe magnet over bars previously hardened and prepared.

In making bar (or straight) magnets, the bars must be laid lengthwise, on a flat table, with the marked end of one bar against the unmarked end of the next; and in making horse-shoe magnets, the pieces of steel previously bent into their proper form, must be laid with their ends in contact, so as to form a figure like two capital U's, with their tops joined together, thus ⊂⊃, observing that the marked ends come opposite to those which are not marked; and then, in either case, a strong horse-shoe magnet is to be passed with moderate pressure over the bars; taking care to let the marked end of this magnet precede, and its unmarked end follow it; and to move it constantly over the steel bars, so as to enter or commence the process at a mark, and then to proceed to an unmarked end, and enter the next bar at its marked end, and so proceed.

After having thus passed over the bars ten or a dozen times on each side, and in the same direction, as to the marks, they will be converted into tolerably strong and permanent magnets. But if, after having continued the process for some time, the exciting magnet is moved *even once* over the bars in a contrary direction, or if its south pole should be permitted to precede, after the north pole has been first used, all the previously excited magnetism will disappear, and the bars will be found in their original state.

What is a magnetic magazine? How is a magnetic needle made? What is said with regard to a horse-shoe magnet? 431. Of what does electro-magnetism treat?

432. The passage of the two kinds of electricity, (namely, the positive and the negative,) through their circuit, is called the electric currents; and the science of electro-magnetism explains the phenomena attending those currents.

It has already been stated, that from the connecting wires of the galvanic circle, or battery, there is a constant current of electricity passing from the zinc to the copper, and from the copper to the zinc plates. In the single circle these currents will be negative from the zinc, and positive from the copper; but in the compound circles, or the battery, the current of positive electricity will flow from the zinc to the copper, and the current of negative electricity from the copper to the zinc.

433. From the effect produced by electricity, on the magnetic needle, it had been conjectured, by a number of eminent philosophers, that magnetism, or magnetic attraction is in some manner caused by electricity. In the year 1819, Professor Oersted, of Copenhagen, made the grand discovery of the power of the electric current to induce magnetism; thus proving the connexion between magnetism and electricity.

434. In a short time after the discovery of Professor Oersted, Mr. Farraday discovered that an electrical spark could be taken from a magnet; and thus the common source of magnetism and electricity was fully proved.

In a paper recently published, this distinguished philosopher has very ably maintained the identity of common electricity, voltaic electricity, magnetic electricity, (or electro-magnetism,) thermo-electricity,* and animal electricity. The phenomena exhibited in all these five kinds of electricity, differ merely in degree and the state of intensity in the action of the fluid.

* In the year 1822, Professor Seebeck, of Berlin, discovered that currents of electricity might be produced by the partial application of heat to a circuit composed exclusively of *solid* conductors. (*See Galvanism, No.* 403.) The electrical current, thus excited, has been termed *Thermo-electric*, (from the Greek *Thermos*, which signifies heat,) to distinguish it from the common galvanic current; which, as it requires the intervention of a *fluid* element, was denominated a *Hydro-electric* current. The term *Stereo-electric* current has also been applied to the former, in order to mark its being produced in systems formed of *solid* bodes alone. It is

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432. What is the electric current? What does the science of electro-magnetism explain? What is the difference between the currents in the single and the compound circles? 433. What is it thought causes magnetic attraction? What discovery was made in the year 1819? By whom? 434. What farther discovery was made soon after, and by whom? What does this philosopher maintain? How do the phenomena exhibited in these five kinds of electricity differ? In what way may currents of electricity be produced? What is the electrical current, thus excited, termed? How does this current differ from the common galvanic current? What other term has been applied to this current?

The discovery of Professor Oersted has been followed out by Ampère; who, by his mathematical and experimental researches, has presented a theory of the science less obnoxious to objections than that proposed by the Professor.

435. The principal facts in connexion with the science of electro-magnetism are,—

1. That the electric current, passing *uninterruptedly** through a wire, connecting the two ends of a galvanic battery, produces an effect upon the magnetic needle.
2. That electricity will induce magnetism.
3. That a magnet, or a magnetic magazine, will induce electricity.
4. That the combined action of electricity and magnetism, as described in the science, produces a rotatory motion of certain kinds of bodies, in a direction pointed out by certain laws.
5. That the periodical variation of the magnetic needle, from the true meridian, or, in other words, the variation of the compass is caused by the influence of the electric currents.
6. That the magnetic influence is not confined to iron, steel, &c. (*See Magnetism, No.* 419,) but that most metals, and many other substances may be converted into temporary magnets by electrical action.
7. That the magnetic attraction of iron, steel, &c. may be prodigiously increased by electrical agency.
8. That the *direction* of the electric current may, in all cases, be ascertained.†

evident that if, as is supposed in the theory of Ampere, magnets owe their peculiar properties to the continual circulation of electric currents in their minute parts, these currents will come under the description of the *stereo-electric* currents.

From the views of electricity which have now been given, it appears that there are, strictly speaking, *three states* of electricity. That derived from the common electrical machine is in the highest degree of tension, and accumulates until it is able to force its way through the air, which is a perfect non-conductor. In the galvanic apparatus, the currents have a smaller degree of tension; because, although they pass freely through the metallic elements, they meet with some impediments in traversing the *fluid* conductor. But in the thermo-electric currents, the tension is reduced to nothing; because, throughout the whole course of the circuit, no impediment exists to its free and uniform circulation.

* All the effects of electricity and galvanism, that have hitherto been described have been produced on bodies *interposed* between the extremities of conductors, proceeding from the positive and negative poles. It was not known, until the discoveries of Professor Oersted were made, that any effect could be produced when the electric circuit is *uninterrupted.*

† This is done by means of the magnetic needle. If a sheet of paper be placed over a horse-shoe magnet, and fine black sand, or steel filings, be dropped loosely on the paper, the particles will be disposed to arrange themselves in a regular order, and in the direction of curve lines. This is, undoubtedly, the effect of some influence, whether that of electricity, or of magnetism alone, cannot at present be determined.

To what do magnets owe their peculiar properties? What follows from this? How many states of electricity are there? What is said of that derived from the common electrical machine? What is said of that derived from the galvanic apparatus? What is said of the thermo electric currents? 435. What are the principal facts in connexion with the science of electro-magnetism? 1. What is the first? 2. What is the second? 3. What is the third? 4. What is the fourth? 5. What is the fifth? 6. What is the sixth? 7. What is the seventh? 8 What is the eighth? Where have the bodies been placed, in all the effects of electricity and galvanism that have hitherto been described?

9. That magnetism is produced whenever concentrated electricity is passed through space.

10. That while in common electrical and magnetic attractions and repulsions, those of the same name are mutually repulsive, and those of different names attract each other; in the attractions and repulsions of *electric currents*, it is precisely the reverse, the repulsion taking place only when the wires are so situated that the currents are in *opposite direction.*

436. A metallic wire, forming a part of a voltaic circuit, exercises a peculiar attraction towards a magnetic needle.

Illustration. If a wire, which connects the extremities of a voltaic battery, be brought over, and parallel with a magnetic needle at rest, or with its poles properly directed north and south, that end of the needle next to the negative pole of the battery will move towards the west, whether the wire be on one side of the needle or the other, provided, only, that it be parallel with it.

Again: If the connecting wire be lowered on either side of the needle, so as to be in the horizontal plane in which the needle should move, it will not move in that plane, but will have a tendency to revolve in a *vertical* direction; in which, however, it will be prevented from moving, in consequence of the attraction of the earth, and the manner in which it is suspended. When the wire is to the east of the needle, the pole nearest to the negative extremity of the battery will be elevated; and when it is on the west side, that pole will be depressed.

If the connecting wire be placed below the plane in which the needle moves, and parallel with it, the pole of the needle next to the negative end of the wire will move towards the east; and the attractions and repulsions will be the reverse of those observed in the former case.

437. The two sides of an unmagnetised steel needle will become endued with the north and south polarity, if the needle be placed parallel with the connecting wire of a voltaic battery, and nearly or quite in contact with it. But if the needle be placed at right angles with the connecting wire, it will become permanently magnetic; one of its extremities pointing to the north pole and the other to the south, where it is freely suspended and suffered to vibrate undisturbed.

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9. What is the ninth fact in connexion with the science of electro-magnetism? 10. What is the tenth? How can the direction of the electric current be ascertained? 436. What is stated in No. 436? What illustration of this is given? What second illustration is given? Where will the pole of the needle next to the negative end of the wire move, if the connecting wire be placed below the plane in which the needle moves, and parallel with it? What is said with regard to the attractions and repulsions? 437. How may the two sides of an unmagnetised steel needle become endued with the north and south polarity? When will it become permanently magnetic?

438. Magnetism may be communicated to iron and steel by means of electricity from an electrical machine; but the effect can be more conveniently produced by means of the voltaic battery.

Illustration. If a *helix* be formed of wire, and a bar of steel be inclosed within the helix, the bar will immediately become magnetic by applying the conducting wires of the battery to the extremities of the helix.* The electricity from the common electrical machine, when passed through the helix, will produce the same effect.

If such a helix be so placed that it may move freely, as when made to float on a basin of water, it will be attracted and repelled by the opposite poles of a common magnet.

439. If a magnetic needle be surrounded by coiled wire, covered with silk, a very minute portion of electricity through the wire will cause the needle to deviate from its proper direction.

A needle thus prepared, is called an electro-magnetic multiplier. It is in fact a very delicate electroscope, or rather *galvanometer* — capable of pointing out the direction of the electric current in all cases.

The discovery of Oersted was limited to the action of the electric current on needles *previously magnetised;* it was afterwards ascertained by Sir Humphrey Davy, and M. Arago, that magnetism may be developed in steel, not previously possessing it, if the steel be placed in the electric current. Both of these philosophers, independently of each other, ascertained that the uniting wire, becoming a magnet, attracts iron filings, and collects sufficient to acquire the diameter of a common quill; but the moment the connexion is broken, all the filings drop off; and the attraction diminishes with the decaying energy of the pile. Filings of brass, or copper, or wood shavings, are not attracted at all.

440. Among the most remarkable of the facts connected with the science of electro-magnetism, is what is called the electro-magnetic rotation. Any wire, through which a current of electricity is passing, has a

* The *helix* is a spiral line, or a line in the form of a cork screw. The wire which forms the helix should be coated with some non-conducting substance, such as silk wound round it; as it may then be formed into close coils, without suffering the electric fluids to pass from surface to surface, which would impair its effect.

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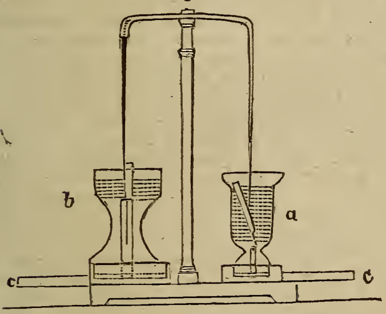
438. How can magnetism be communicated to iron and steel? How can the effect be more conveniently produced? What illustration of this is given? What is the helix? Why should the wire, which forms the helix be eoated with some non-conducting substance? What is said of a helix, if it be placed so that it may move freely? 439. How can the magnetic needle be made to deviate from its proper direction? What is a needle thus prepared called? Can magnetism be developed in steel not previously possessing it? Where must the steel be placed? What property has the uniting wire? What follows, if the connexion be broken? Are filings of brass or wood attracted at all? 440. What is the electro-magnetic rotation?

tendency to revolve round a magnetic pole, in a plane perpendicular to the current; and that without reference to the axis of the magnet, the pole of which is used. In like manner, a magnetic pole has a tendency to revolve round such a wire.

Illustration. Suppose the wire perpendicular, its upper end positive, or attached to the positive pole of the voltaic battery, and its lower end negative; and let the centre of a watch-dial represent the magnetic pole: if it be a north pole, the wire will rotate round it, in the direction that the hands move; if it be a south pole, the motion will be in the opposite direction. From these two, the motions which would take place if the wire were inverted, or the pole changed, or made to move, may be readily ascertained, since the relation now pointed out remains constant.

Fig. 131 represents the ingenious apparatus, invented by Mr. Faraday, to illustrate the electro-magnetic rotation. The central pillar supports a piece of thick copper wire, which, on the one side, dips into the mercury contained in a small glass cup *a*. To a pin at the bottom of this cup, a small cylindrical magnet is attached by a piece of thread, so that one pole shall rise a little above the surface of the mercury, and be at liberty to move around the wire. The bottom of the cup is perforated, and has a copper pin passing through it; which, touching the mercury on the inside, is also in contact with the wire that proceeds outwards, on that side of the instrument. On the other side of the instrument, *b*, the thick copper wire, soon after turning down terminates, but a thinner piece of wire forms a communication between it and the mercury on the cup beneath. As freedom of motion is regarded in the wire, it is made to communicate with the former by a ball and socket joint; the ball being held in the socket by a piece of thread; or else, the ends are bent into hooks, and the one is then hooked to the other. As good metallic contact is required, the parts should be amalgamated, and a small drop of mercury placed between them; the lower ends of the wire should also be amalgamated. Beneath the

Fig. 131.



What illustration is given? What does fig. 131 represent? Explain the figure? How is the freedom of motion, which is required on the wire, obtained? How can the metallic contact, which is required, be obtained?

hanging wire, a small circular magnet is fixed in the socket of the cup *b*, so that one of its poles is a little above the mercury. As in the former cup, a metallic connexion is made, through the bottom, from the mercury to the external wire.

If now the poles of a battery be connected with the horizontal external wires, *c*, *c*, the current of electricity will be through the mercury and the horizontal wire, on the pillar which connects them, and it will now be found, that the moveable part of the wire will rotate around the magnetic pole in the cup *b*, and the magnetic pole round the fixed wire in the other cup *a*, in the direction before mentioned.

By using a very delicate apparatus, the magnetic pole of the earth may be made to put the wire in motion.

Fig. 132 represents another ingenious contrivance, invented by M. Ampère, for illustrating the electro-magnetic rotation; and it has the advantage of comprising within itself the voltaic combination which is employed. It consists of a cylinder of copper, about two inches high, and a little less than two inches internal diameter, within which, is a smaller cylinder, about one inch in diameter. The two cylinders are fixed together by a bottom, having a hole in its centre, the size of the smaller cylinder, leaving a circular cell, which may be filled with acid. A piece of strong copper wire is fastened across the top of the inner cylinder, and from the middle of it, rises, at a right angle, a piece of copper wire, supporting a very small metal cup, containing a few globules of mercury. A cylinder of zinc, open at each end, and about an inch and a quarter in diameter, completes the voltaic combination. To the latter cylinder, a wire bent like an inverted U, is soldered, at opposite sides; and in the bend of this wire a metallic point is fixed, which, when inserted in the little cup of mercury, suspends the zinc cylinder in the cell, and allows it a free circular motion. An additional point is directed downwards from the central part of the stronger wire, which point is adapted to a small hole at the top of a powerful bar magnet. When the apparatus with *one* point only is charged with diluted acid, and set on the magnet placed vertically, the zinc cylinder revolves in a direction determined by the magnetic pole which is uppermost. With two points, the copper revolves in one direction, and the zinc in a contrary direction.

Fig. 132.

If instead of a bar magnet, a hors-eshoe magnet be employed, with an apparatus on each pole, similar to that which has now been described, the cylinders in each will revolve in opposite directions. The small cups of mercury mentioned in the preceding description are sometimes omitted, and the points are inserted in an indentation on the inverted U.

If the poles of a battery be connected with the horizontal external wires, *c c*, throughout, what will the current of electricity be? Round what pole will the movable part of the wire rotate? Round what will the magnetic pole rotate? What does fig. 132 represent? Of what does it consist? How will the cylinders in each revolve, if instead of a bar magnet a horse-shoe magnet be employed, with an apparatus on each pole similar to that which has now been described?

441. Magnets of prodigious power have been formed by means of Voltaic electricity.

An electro-magnet was constructed by Professor Henry and Dr. Ten Eyck, which was capable of supporting a weight of 750 pounds. They have subsequently constructed another, which will sustain 2063 pounds, or nearly a ton. It consists of a bar of soft iron, bent into the form of a horse shoe, and wound with twenty-six strands of copper bell-wire, covered with cotton threads, each thirty-one feet long; about eighteen inches of the ends are left projecting, so that only twenty-eight feet of each actually surround the iron. The aggregate length of the coils is therefore 728 feet. Each strand is wound on a little less than an inch: in the middle of the horse shoe it forms three thicknesses of wire; and on the ends, or near the poles, it is wound so as to form six thicknesses. Being connected with a battery consisting of plates, containing a little less than 48 square feet of surface, the magnet supported the prodigious weight stated above, namely 2063 pounds. The effects of a larger battery were not tried.

442. It is seen, by what has just been stated, that magnetism, of great power, is induced by electricity. It remains now to be stated that electricity, of considerable power, can be elicited from a magnet.

This discovery was made, (as has already been stated) by Mr. Faraday. The experiment may be made in the following manner. Twelve sheer steel plates are to be connected in the form of a horse shoe; with a keeper or lifter made of the purest soft iron. Around the middle of the keeper is a wooden winder, having about a hundred yards of common thread bonnet wire, the two ends composed of four lengths of the wire twisted together, being carved out with a vertical curve of about three fourths of a circle; one of these twisted ends passing beyond each end of the keeper, and resting on the respective poles of the magnet. A small wooden lever is so fixed as to admit of the winder and the keeper being suddenly separated from contact with the magnet, when a beautiful and brilliant spark is perceived to issue from the extremity of the wire which first becomes separated from the magnet. By means of this electro-magnetic spark, gunpowder may be inflamed.*

* A magneto-electrical machine has been constructed by Mr. J. Saxton, an ingenious mechanic of Philadelphia, resident in London. A similar apparatus has been made by Mr. J. Lukens, of Philadelphia, in a very neat and portable form, and it serves to demonstrate the nature of the reaction between magnets and electrical currents. Messrs. A. & D. Davis, of this city, have lately constructed an apparatus of the same kind, for Dr. Webster, Professor of Chemistry in Harvard University.

Dr. Ritchie, Professor of Natural Philosophy in the University of London, has

441. How have magnets of great power been formed? What weight was the magnet constructed by Professor Henry and Dr. Ten Eyck, capable of supporting? What weight will the one afterwards constructed sustain? Of what does it consist? 442. By what is magnetism of great power induced? From what can electricity of considerable power be elicited? By whom was this discovery made? How can the experiment be made? Who has succeeded in an attempt to cause the continued rotation of a temporary magnet? How is this effect produced?

The science of Electro-magnetism is yet in its infancy. The discoveries which have rewarded the laborers of philosophical research are truly wonderful;—but man has as yet but lifted the veil, behind which the stupendous operations of nature are carried on. What wonders he will discover, should he penetrate the recesses of her laboratory, imagination cannot conceive. It would have excited no little surprise, among the philosophers of the last century, had the opinion been advanced, that Electricity and Magnetism are identical. Perhaps the future philosopher may surprise a generation not very distant, by the annunciation of the discovery, that attraction and repulsion *of all kinds*, are to be traced to a common source,—that the same influence which binds the particles of a grain of sand together, *is seen* in the vivid flash which causes the "lit lake to shine;" or *heard* in the "live thunder," as it leaps from peak to peak; or known in the unerring guide which it furnishes the mariner in his course over the trackless deep; and admired in the *music* of the spheres, as they *harmoniously* roll in grand and magnetic course in the immeasurable regions of infinite space.

SECTION XX.

Astronomy.

443. Astronomy treats of the heavenly bodies, such as the sun, moon, stars, comets, planets, &c.

444. The earth on which we live is a large globe, or ball, nearly eight thousand miles in diameter, and about twenty-five thousand miles in circumference. It is

succeeded in an attempt to cause the continued rotation of a temporary magnet on its centre, by the action of permanent magnets. This effect is produced by suddenly changing the poles of the temporary magnet, and thus, at the proper moment, converting attraction into repulsion.

Professor Henry, of Princeton, New Jersey, has constructed an apparatus for exhibiting, in a temporary magnet, a reciprocating motion. The soft iron magnet, with its coils of wire, is suspended like the beam of a steam engine, on an axis, and furnished with projecting wires, which dip into mercurial cups, connected with a voltaic battery at each end of the apparatus. The wires are so arranged as to change the poles of the soft magnet at every alternation in the movement. Each end of the soft iron bar plays between the poles of a permanent magnet, curved into an elliptical form; and as it dips into the mercurial cup below, its polarity is changed, and it is repelled. A vigorous action is thus kept up, which is limited only, by the durability of the materials in the galvanic circuit, and their power of furnishing a supply of electricity.

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43. Of what does astronomy treat? 444. What is said of the earth?

known to be round—*first*, because it casts a circular shadow, which is seen on the moon, during an eclipse; *secondly*, because the upper parts of distant objects on its surface, can be seen at the greatest distance; *thirdly*, it has been circumnavigated. It is situated in the midst of the heavenly bodies, which we see around us at night, and forms one of the number of those bodies; and it belongs to that system, which, having the sun for its centre, and being influenced by its attraction, is called the *solar** system.

445. The solar system consists of the sun, which is in the centre.

Of seven *primary* planets, named Mercury, Venus, the Earth, Mars, Jupiter, Saturn, and Herschel;†

Of four Asteroids, or smaller planets, namely, Ceres, Pallas, Juno, and Vesta;

Of eighteen secondary planets or moons, of which the Earth has one, Jupiter four, Saturn seven, and Herschel six; and

Of an unknown number of comets.

446. The stars, which we see in the night time, are supposed to be suns, surrounded by systems of planets, &c. too distant to be seen from the earth. Although they appear so numerous on a bright night, yet there are never more than a thousand visible to the sight, unassisted by glasses. The various refractions and reflections of the atmosphere make them appear much more numerous than they really are.

447. Among the stars that are visible on a clear night may be seen a number which are called *planets*,‡ (*mentioned in No.* 445.) The planets may be distinguished from the stars by their *steady* light; while the stars are constantly *twinkling*. The planets, likewise, appear to

* The word *solar* means belonging to the sun.

† This planet is sometimes called Uranus, and sometimes the Georgium Sidus.

‡ The meaning of the word planet is properly a *wanderer*, or a *wandering star*. These luminaries were so called because they never retain the same situation, but are constantly changing their relative positions. While those stars which appear to retain their places are called *fixed* stars. The cause of the motion of the planets will be presently explained.

How is the earth known to be round? How is it situated? 445. Of what does the solar system consist? 446. What are the stars supposed to be? How many are visible, on a bright night, unassisted by glasses? Why do they appear so numerous? 447. How may the planets be distinguished from the stars? How are the planets distinguished from the *fixed* stars? What is the meaning of the word planet? Why are they called planets? What are the fixed stars?

change their relative places in the heavens, while those luminous bodies which are called *fixed* stars appear to preserve the same relative position.

448. The sun, the moon, the planets, and the fixed stars, which appear to us so small, are supposed to be large worlds, of various sizes, and at different but immense distances from us. The reason that they appear to us so small is, that on account of their immense distances they are seen under a small angle of vision.—[*See Optics, page* 125, *No.* 340.]

449. It has been stated in the first part of this book, (*See pages* 13 *and* 14, *Nos.* 43, 44 *and* 45,) that *every portion of matter* is attracted by every other portion—and that the force of the attraction depends upon the *quantity* and the *distance.* On account of the immense distance of these heavenly bodies from the earth they will not fall, like other bodies, to its surface—and besides, if they *were* sufficiently near, the earth would rather fall upon one of them, because some of them are larger than the earth. As attraction, however, is *mutual* we find that all of the heavenly bodies attract the earth ; and the earth, likewise, attracts all of the heavenly bodies. It has been proved, (*see page* 34, *Nos.*126 *and* 127,) that a body when actuated by several forces will not obey *either one*, but will move in a direction *between* them. It is so with the heavenly bodies—each one of them is attracted by every other one ; and these attractions are so nicely balanced by creative wisdom, that, instead of rushing together in one mass, they are caused to move in regular paths, (called *orbits*,) around a central body; which being attracted in *different* directions, by the bodies which revolve around it, will itself revolve around the centre of gravity of the system. Thus, the sun is the centre of what is called the *solar* system, (*see No.* 445,) and the planets revolve around it in different times, at different distances, and with different velocities. [*See No.* 78, *page* 21.]

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448. What are the sun, moon, planets and fixed stars supposed to be? Why do they appear so small? 449. What has been stated with regard to the attraction of portions of matter? Upon what does the force of this attraction depend? Why do not the heavenly bodies fall, like other bodies, to the surface of the earth? What follows from attraction being mutual? What direction do bodies take when actuated by several forces? Is this true with regard to the heavenly bodies? What is meant by the orbit of a planet? What is the centre of the solar system? What is said of the revolution of the planets?

450. The paths or courses in which the planets move around the sun are called their orbits. In obedience, therefore, to the universal law of gravitation, or gravity, the planets revolve around the sun as the centre of their system; and the time that each one takes to perform an entire revolution is called its year. Thus, the planet Mercury revolves around the sun in 87 of our days. Hence, a year on that planet is equal to 87 days. The planet Venus revolves around the sun in 224 days. That is, therefore, the length of the year of that planet. Our earth revolves around the sun in about 365 days and 6 hours. Our year, therefore, is of the same length.

451. The length of time that each planet takes in performing its revolution around the sun, or, in other words, the length of the year on each planet is as follows. (*The fractional parts of the day are omitted.*)

Mercury	87 days.	Vesta	1,325 days.	Jupiter	4,332 days.
Venus	224 "	Juno	1,592 "	Saturn	10,759 "
Earth	365 "	Ceres	1,681 "	Herschel	30,686 "
Mars	686 "	Pallas	1,686 "		

452. The mean distance* of each of the planets from the sun is expressed as follows, in millions of miles.

	Millions.		Millions.		Millions.
Mercury	36 "	Vesta	225 "	Jupiter	495 "
Venus	68 "	Juno	254 "	Saturn	908 "
The Earth	95 "	Ceres	263 "	Herschel	1,827 "
Mars	145 "	Pallas	264 "		

* The paths or orbits of the planets are not exactly circular, but elliptical. They are, therefore, sometimes nearer to the sun than at others. The mean distance is the medium, between their greatest and least distance. Those planets which are nearer to the sun than the earth is, are called interior planets, because their orbits are within that of the earth—and those which are farther from the sun are called exterior planets, because their orbits are outside that of the earth. Instead of *interior* and *exterior*, the names *inferior* and *superior* are sometimes used.

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450. What are the paths, in which the planets move around the sun, called? Around what do the planets revolve? What is a year on each planet? How long is the year of the planet Mercury? How long is the planet Venus performing her revolution around the sun? How long is the earth in performing her revolution around the sun? 451. What is the length of a year on the planet Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? 452. What is the distance of the planet Mercury from the Sun? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? Of what form are the orbits of the planets? What is meant by the mean distance? What planets are called interior? Why? What planets are called exterior? Why? What other names are sometimes used?

453. While the planets revolve around the sun, each also turns around upon its own axis, and thus presents each side successively to the sun. The time in which they turn upon their axes is called their day, and is thus expressed in hours and minutes:

	H.	M.		H. M.		
Mercury	24 "	5 "	Vesta	(*unknown.*)	Jupiter	9 h. 55 m.
Venus	23 "	20 "	Juno	27 (*probably*)	Saturn	10 " 16 "
Earth	22 "	56 "	Ceres	(*unknown.*)	Herschel	(*unknown.*)
Mars	24 "	39 "	Pallas	(*unknown.*)		

The sun turns on its axis in about 25 days and 10 hours.

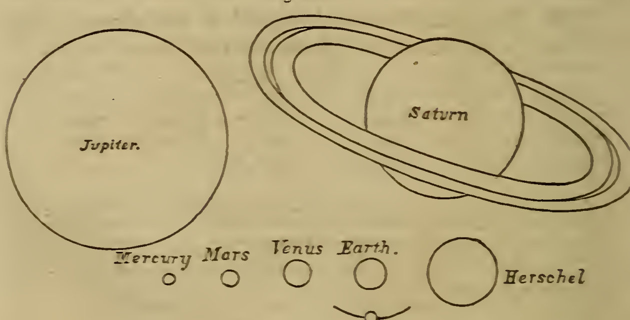
454. The relative size of the bodies belonging to the solar system, as expressed by the length of their diameters, is as follows:

	Miles.		Miles.		Miles.
The Sun	877,547	Mars	4,222	Pallas	2,025
Mercury	2,984	Vesta	269	Jupiter	86,255
Venus	7,621	Juno	1,393	Saturn	81,954
Earth	7,924	Ceres	1,582	Herschel	34,363

The Moon 2,180 miles.

Fig.133 is a representation of the comparative size of the planets. The following illustration of the comparative size and distance of

Fig. 133.



the bodies of the solar system is given by Sir J. F. W. Herschel. On a well levelled field place a globe, two feet in diameter, to represent the Sun; Mercury will be represented by a grain of mustard

453. Have the planets any motion beside that around the sun? What is the time in which they turn upon their axes called? What is the length of a day on the planet Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? 454. What is the diameter of the Sun? Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Herschel? The Moon? What does fig. 133 represent? What illustration of the comparative size and distance of the bodies of the solar system is given?

seed on the circumference of a circle 164 feet in diameter for its orbit;—Venus, a pea, on a circle 284 feet in diameter; the Earth also a pea, on a circle of 430 feet; Mars, a rather large pin's head, on a circle of 654 feet; Juno, Ceres, Vesta and Pallas, grains of sand, in orbits of from 1000 to 1200 feet; Jupiter, a moderate sized orange, in a circle nearly half a mile in diameter;—Saturn, a small orange, on a circle of four-fifths of a mile in diameter, and Herschel a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half in diameter.

"To imitate the motions of the planets in the above mentioned orbits, Mercury must describe its own diameter in 41 seconds; Venus in 4 minutes and 14 seconds, the Earth in 7 minutes, Mars in 4 minutes and 48 seconds, Jupiter in 2 hours 56 minutes, Saturn in 3 hours 13 minutes, and Herschel 12 hours 16 minutes."

455. The orbit of the earth is called the ecliptic. In other words, the ecliptic is the apparent path of the sun, or the real path of the earth. It is called the ecliptic, because every *eclipse*, whether of the sun or the moon, must be upon it. The zodiac is a broad space or belt, 16 degrees broad, 8 degrees each side of the ecliptic. It is called the *zodiac*, from a Greek word, which signifies *an animal*, because all the stars in the twelve parts into which the ancients divided it, were formed into one sign or constellation, and most of the twelve constellations were called after some animal. The names of these constellations or signs are sometimes given in Latin and sometimes in English. They are as follows:

	Latin.	English.		Latin.	English.
1	Aries	The Ram.	7	Libra	The Balance.
2	Taurus	The Bull.	8	Scorpio	The Scorpion.
3	Gemini	The Twins.	9	Sagittarius	The Archer.
4	Cancer	The Crab.	10	Capricornus	The Goat.
5	Leo	The Lion.	11	Aquarius	The Water-bearer.
6	Virgo	The Virgin.	12	Pisces	The Fishes.

Each sign or constellation contains 30 degrees of the great celestial circle.*

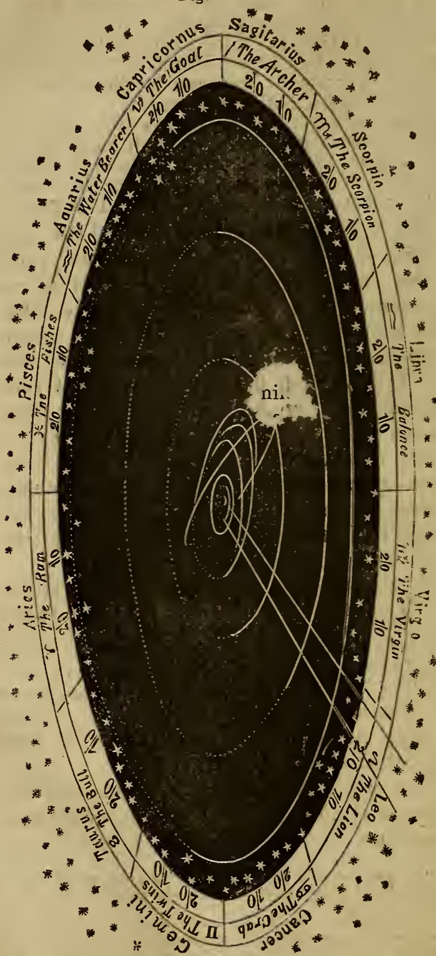
456. The orbits of the other planets are inclined to that of the earth; or, in other words, they are not in the same plane.

*Owing to the precession of the equinoxes, the stars which were formerly in the constellation called Aries, are now in the one called Taurus, &c., each having gone forward one sign.

What is necessary in order to imitate the motions of the planets in the above mentioned orbits? 455. What is the orbit of the earth called? What is the ecliptic? Why is it called the ecliptic? What is the zodiac? Why is it called the zodiac? What are the names of the twelve constellations? How many degrees does each sign contain? 456. Are the orbits of the other planets in the same plane with that of the earth?

Figure 134 represents an oblique view of the plane of the ecliptic, the orbits of all the primary planets, and of the comet of 1680. That

Fig. 134.



part of each orbit which is above the plane is shown by a white line; that which is below it, by a dark line. That part of the orbit

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What does fig. 134 represent?

of each planet where it crosses the ecliptic, or, in other words, where the white and dark lines in the figure meet, are called the nodes of the planet. [From the Latin *nodus*, a knot or tie.]

Fig. 135.

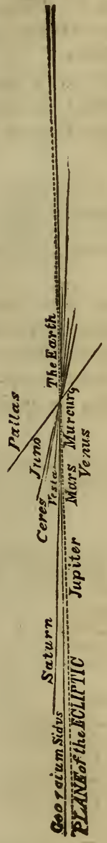

Figure 135 represents a section of the plane of the ecliptic, showing the inclination of the orbits of the planets. As the zodiac extends only eight degrees on each side of the ecliptic, it appears from the figure that the orbits of some of the planets are wholly in the zodiac, while those of others rise above and descend below it. Thus, the orbits of Juno, Ceres, and Pallas rise above, &c., while those of all the other planets are confined to the zodiac.

When a planet or heavenly body is in that part of its orbit which is near any particular constellation, it is said to be in that constellation. Thus in Fig. 134, the comet of 1680 appears to approach the sun from the constellation Leo.

457. The perihelion* and aphelion* of a heavenly body express its situation with regard to the sun. When a body is nearest to the sun, it is said to be in its perihelion. When farthest from the sun, it is said to be in its aphelion. [*See note to No.* 452.] The earth is three millions of miles nearer to the sun in its perihelion, than in its aphelion.

458. The apogee and perigee of a heavenly body express its situation with regard to the earth. When the body is nearest to the earth, it is said to be in its perigee; when it is farthest from the earth, it is said to be in its apogee.

459. The aphelia of the planets, or parts of their orbits in which they are nearest to

* The plural of ***Perihelion*** is ***Perihelia***, and of ***Aphelion*** is ***Aphelia***. When a planet is so nearly on a line with the earth and the sun as to pass between them, it is said to be in its *inferior conjunction*; when behind the sun, it is said to be in its *superior conjunction*; but when behind the earth it is said to be in *opposition*.

What are the nodes of a planet? What does fig. 136 represent? When is a planet said to be in any particular constellation? 457. What do the perihelion and aphelion of a heavenly body express? When is a body said to be in its perihelion? When is it said to be in its aphelion? How much nearer is the earth to the sun in its perihelion than its aphelion? When is a planet said to be in its inferior conjunction? When is it said to be in its superior conjunction? When is it said to be in opposition? 457. What do the apogee and perigee of a heavenly body express? When is a body said to be in its perigee? When is it said to be in its apogee?

the sun (*See note to No.* 452) are in the following signs of the zodiac :—Mercury in *Sagittarius*—Venus in *Aquarius*—the Earth in *Capricornus*—Mars in *Virgo*—Vesta in *Cancer*—Juno in *Scorpio*—Ceres in *Pisces*—Pallas in *Aquarius*—Jupiter in *Libra*—Saturn in *Capricornus*—and the Georgium Sidus in *Aries*.*

460. The axes of the planets in their revolution around the sun, are not perpendicular to their orbits, nor to the plane of the ecliptic, but are inclined in different degrees.

This is one of the most remarkable circumstances in the science of Astronomy, because it is the cause of the different seasons, spring, summer, autumn and winter; and because it is also the cause of the difference in the length of the days and nights in the different parts of the world, and at the different seasons of the year.

461. The motion of the heavenly bodies is not uniform. Their velocity is different in different parts of their orbits. They move with the greatest velocity when they are *in perihelion*, or in that part of their orbit which is nearest to the sun; and slowest when *in aphelion.*

It has been proved by Kepler, that in moving round a point towards which it is attracted, *a body passes over equal areas in equal times.* This is called Kepler's law.

* The signs of the Zodiac and the various bodies of the solar system, are often represented in Almanacks and Astronomical works, by signs or characters. In the following list the characters of the planets &c. are represented.

☉ The Sun.	⊕ The Earth.	⚳ Ceres.
☾ The Moon.	♂ Mars.	⚴ Pallas.
☿ Mercury.	⚶ Vesta.	♃ Jupiter.
♀ Venus.	⚵ Juno.	♄ Saturn.
	♅ Herschel.	

The following characters represent the signs of the Zodiac.

♈ Aries.	♋ Cancer.	♎ Libra.	♑ Capricornus.
♉ Taurus.	♌ Leo.	♏ Scorpio.	♒ Aquarius.
♊ Gemini.	♍ Virgo.	♐ Sagittarius.	♓ Pisces.

From an inspection of the figure. it appears that when the earth, as seen from the sun, is in any particular constellation, the sun, as viewed from the earth, will appear in the opposite one.

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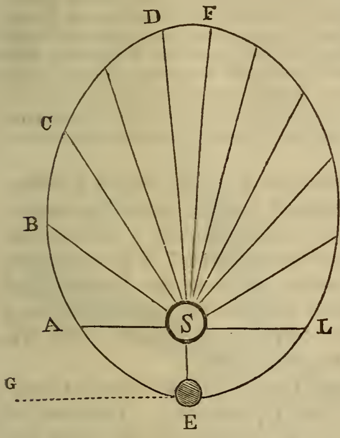
459. In what sign is the aphelion of the planet Mercury? Venus? Earth? Mars? Vesta? Juno? Ceres? Pallas? Jupiter? Saturn? Georgium Sidus? 460. What is said with regard to the axes of the planets in their revolution around the sun? What does this inclination of their axes cause? 461. What is said with regard to the motion of the heavenly bodies? When do they move with the greatest velocity? When is their motion the slowest? What is Kepler's law?

Illustration. In fig. 136, let S represent the Sun, and E the Earth, and the ellipse or oval be the earth's orbit or path around the Sun. By lines drawn from the Sun at S to the outer edge of the figure, the orbit is divided into twelve areas (or parts) of different shapes, but each containing the same quantity of space. Thus, the spaces E S A, A S B, D S F, &c. are all supposed to be equal. Now if the earth, in the space of one month will move in its orbit from E to A, it will in another month move from A to B, and in the third month from B to C, &c.; and thus will describe (or rather more properly speaking, *pass by*) equal areas in equal times.

Fig. 136.



The reason why the earth (or any other heavenly body) moves with a greater degree of velocity in its perihelion, than in its aphelion, may likewise be explained by the same figure. Thus:

The Earth in its progress from F to L, being *constantly* actuated by the sun's attraction, must, (as is the case with a stone when falling to the earth,) (*See No.* 110,) move with an accelerated motion. At L, the sun's attraction becomes stronger, on account of the nearness of the earth; and consequently in its motion from L to E, the earth will move with greater rapidity. At E, which is the perihelion of the earth, it acquires its greatest velocity. Let us now detain it at E, merely to consider the direction of the forces by which it is actuated. If the sun's attraction could be destroyed, the force which has carried it from L to E, would carry it off in the dotted line from E to G, which is a tangent to its orbit. But while the Earth has this tendency to move towards G, the sun's attraction is continually operating, with a tendency to carry it to S. Now when a body is actuated by two forces, (*See No.* 126,) it will move between them; but as the sun's attraction is constantly exerted at right angles to the motion of the earth, the direction of the earth's motion will not be in a straight line, the diagonal of *one* large parallelogram, but through the diagonal of a number of infinitely small parallelograms; which, being united, form the curve line E A.

It is thus seen, that while the earth is moving from L to E, and from E to A, the attraction of the sun is stronger than in any other part of its orbit, and will cause the earth to move rapidly. But in

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Illustrate this by fig. 136. Explain, by fig. 136, the reason why the earth, or any other heavenly body, moves with a greater degree of velocity in its perihelion than in its aphelion?

its motion from A to B, from B to C, and from C to F, the attraction of the sun, operating in an opposite direction, will cause its motion from the sun to be retarded until, at F, the direction of its motion is reversed, and it begins again to approach the sun. Thus, it appears that in its passage from the Perihelion to the Aphelion, the motion of the earth, as well as that of all the heavenly bodies must be constantly retarded—while in moving from their Aphelion to Perihelion, it is constantly accelerated; and at their Perihelion, their velocity will be the greatest. The earth therefore, is about seven days longer in performing the aphelion part of its orbit, than in traversing the perihelion part; and the revolution of all the other planets being the result of the same cause, is affected in the same manner as that of the earth.

462. The central forces (*see No.* 129) which produce the revolution of the heavenly bodies around a common centre, are both the result of *gravitation*. The attraction of the sun is the *centripetal* force. The attraction of the other heavenly bodies, such as the planets, and even the very remote stars and comets, operating in a different direction, is the *centrifugal force.** [*See No.* 78, *page* 21, *and No.* 449, *page* 190.]

463. The earth is about three millions of miles nearer to the sun in winter than in summer. The heat of summer, therefore, cannot be caused by the near approach of the earth to the sun.

Snow and ice never melt on the tops of high mountains; and they who have ascended in the atmosphere, in balloons, have found that the cold increases as they rise.

464. On account of the inclination of the earth's axis, (*see No.* 460) the rays of the sun fall more or less obliquely on different parts of the earth's surface, at different seasons of the year. The heat is always the greatest when the sun's rays fall *vertically*, that is, perpendicular; and the more obliquely they fall, the less heat they appear to possess.

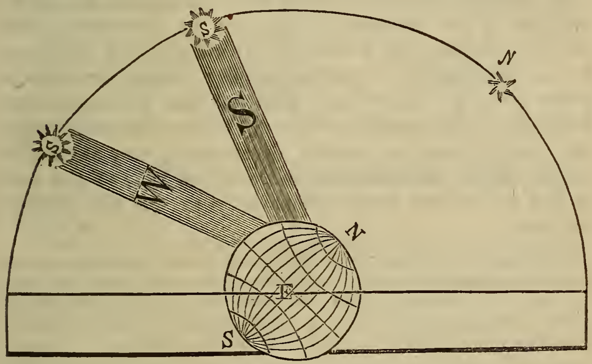
* In many treatises on this subject, mention is made of a *projectile force*. As, however, all the harmonious motions, revolutions, &c., of the various bodies can be satisfactorily explained on the principle of *gravitation alone*, and as the use of the word projectile is obnoxious to the objection that it conveys a misrepresentation of the truth, it has in this work been purposely avoided.

What is said of the motion of the heavenly bodies from perihelion to aphelion? What is their motion from aphelion to perihelion? When is their velocity the greatest? How much longer is the earth in performing the aphelion part of its orbit than the perihelion part? 462. Of what are the central forces, which produce the revolution of the heavenly bodies around a common centre, the result? What is the centripetal force? What is the centrifugal force? 463. How much nearer is the earth to the sun in winter than in summer? 464. What follows from the inclination of the earth's axis, with regard to the direction of the sun's rays? When is the heat always the greatest? What is said of oblique rays?

This is the reason why the days are hotter in summer, although the earth is farther from the sun at that time.

Illustration. Fig. 137 represents the manner in which the rays of the sun fall upon the earth in summer and in winter. The north pole of the earth, at all seasons, constantly points to the north star, N; and when the earth is nearest to the sun, the rays from the sun fall as indicated by W, in the figure; and as their direction is very oblique, and they have a larger portion of the atmosphere to traverse, much of their power is lost. Hence we have *cold* weather

Fig. 137.



when the earth is nearest to the sun. But, when the earth is in aphelion, the rays fall almost vertically, or perpendicularly; and, although the earth is then nearly three million of miles further from the sun, the heat is greatest, because the rays fall more directly, and have a less portion of the atmosphere to traverse.*

For a similar reason, we find, even in summer, that early in the morning, and late in the afternoon, it is much cooler than at noon; because the sun then shines more obliquely. The heat is generally the greatest at about three o'clock in the afternoon; because the earth retains its heat for some length of time, and the additional heat it is constantly receiving from the sun, causes an elevation of temperature, even after the rays begin to fall more obliquely.

* This may be more familiarly explained, by comparing summer rays to a ball or stone thrown directly *at* an object, so as to strike it with all its force;—and winter rays to the same ball or stone, thrown obliquely, so as merely *to graze* the object.

What is the reason that the heat is greater in summer than in winter? Illustrate this by fig. 137. How is the earth situated with regard to its distance from the sun in winter? What illustration of oblique and perpendicular rays is given in the note? Why is it generally cooler early in the morning and late in the afternoon than at noon? Why is the heat the greatest at about three o'clock?

It is the same cause which occasions the variety of climate in different parts of the earth. The sun always shines in a direction nearly perpendicular or vertical on the equator; and with different degrees of obliquity on the other parts of the earth. For this reason, the greatest degree of heat prevails at the equator during the whole year. The farther any place is situated from the equator, the more obliquely will the rays fall, at different seasons of the year; and consequently the greater will be the difference in the temperature.

465. If the axis of the earth were perpendicular to its orbit, those parts of the earth which lie under the equator would be constantly opposite to the sun; and as, in that case, the sun would at all times of the year be vertical to those places equally distant from both poles; so the light and heat of the sun would be dispersed with perfect uniformity towards each pole; we should have no variety of seasons; day and night would be of the same length; and the heat of the sun would be of the same intensity every day throughout the year.

It is, therefore, as has been stated, owing to the inclination of the earth's axis, that we have the agreeable variety of the seasons, days and nights of different lengths, and that wisely ordered variety of climate, which causes so great a variety of productions, and which has afforded so powerful a stimulus to human industry.*

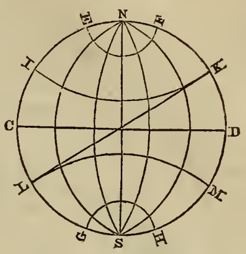
466. In order to understand the *illustration* of the causes of the seasons, &c. it is necessary to have some knowledge of the circles which are drawn on the artificial representations of the earth. It is to be remembered that all of these circles are wholly imaginary—that is, that there is on the earth itself no such circles or lines. They are drawn on maps merely for the purpose of illustration.

* The wisdom of Providence is frequently displayed in *apparent* inconsistencies. Thus, the very circumstances which to the *short-sighted* philosopher appears to have thrown an insurmountable barrier betwen the scattered portions of the human race, has been wisely ordered to establish an interchange of blessings, and to bring the ends of the earth in communion. Were the same productions found in every region of the earth, the stimulus to exertion would be weakened, and the wide field of human labor would be greatly diminished. It is our mutual *wants* which bind us together.

What causes the variety of climate in different parts of the earth? Where does the sun always shine in a vertical direction? 465. What would follow were the axis of the earth perpendicular to its orbit? What causes the variety of the seasons, the different lengths of days and nights, &c. 466. What is necessary in order to understand the illustration of the causes of the seasons?

Fig. 138 represents the earth. N S is the axis, or imaginary line, around which it daily turns; N is the north pole, S is the south pole. These poles, it will be seen, are the extremities of the axis, N S. C D represents the equator, which is a circle around the earth, at an equal distance from each pole.— The curved lines proceeding from N to S, are meridians. They are all circles surrounding the earth, and passing through the poles.— These meridians may be multiplied at pleasure.

Fig. 138.



The lines E F, I K, L M, and G H, are designed to represent circles, all of them parallel to the equator, and for this reason they are called parallels of latitude. These also may be multiplied at pleasure.

But in the figure, these lines, which are parallel to the equator, and which are at a certain distance from it, have a different name, derived from the manner in which the sun's rays fall on the surface of the earth.

Thus the circle I K, 23½ degrees from the equator is called the *tropic* of Cancer, because, when the sun's vertical rays fall upon that portion of the earth, they *turn*,* and proceed backwards towards the equator.

For a similar reason, the circle L M is called the *tropic* of Capricorn.† The circle E F is called the Arctic Circle. It represents the limit of perpetual day, when it is summer in the northern hemisphere, and of perpetual night when it is winter.

The circle G H is the Antarctic Circle, and represents the limit of perpetual day and night in the southern hemisphere. The line L K, represents the circle of the ecliptic, which, (as has already been stated in No. 455,) is the *apparent* path of the sun, or the *real* path of the earth. This circle, although it is generally drawn on the terrestrial globe, is, in reality, a circle in the heavens; and differs from the zodiac only in its width—the zodiac extending eight degrees on each side of the ecliptic. [*See No.* 455, *page* 193.]

Fig. 139 represents the manner in which the sun shines on the earth in different parts of its orbit; or, in other words, the cause of the change in the seasons. S represents the sun, and the dotted oval, or ellipse, A B C D, the orbit of the earth. The outer circle

* The word *tropic* is derived from a word which means *to turn.*

† The tropics, therefore, are the boundaries of the sun's apparent path, north and south of the equator.

Explain fig. 138. What are the poles? Why is the circle I K called the tropic of Cancer? What is the meaning of the word tropic? Why is the circle L M called the tropic of Capricorn? What are the tropics? What is the circle E F called? What does it represent? What is the circle G H called? What does it represent?

represents the zodiac, with the position of the twelve signs or constellations. On the 21st of June, when the earth is at D, the whole northern polar region is continually in the light of the sun. As it

Fig. 139.

turns on its axis, therefore, it will be day to all the parts which are exposed to the light of the sun.* But, as the whole of the Antarctic Circle is within the line of perpetual darkness, the sun can shine on no part of it. It will, therefore, be constant night to all places with-

* Day and night are caused by the rotation of the earth on its axis every 24 hours. It is day to that side of the earth which is towards the sun, and night to the opposite side. The length of the days is in proportion to the inclination of the axis of the earth *towards* the sun. It may be seen by the above figure, that in summer, the axis is most inclined towards the sun, and then the days are the longest. As the axis becomes less inclined, the days shorten, till, on the 21st December, it is inclined 23 1-2° *from* the sun, when the days are the shortest. Thus, as the earth progresses in its orbit, after the days are the shortest, it changes its inclination toward the Sun, till it is again inclined as in the longest days in the summer.

* The engraver has misrepresented the line of perpetual darkness on the earth, at B and D. It should extend from the tropic of Cancer to the tropic of Capricorn; whereas, in the figure. it appears to extend from the North to the South pole. The mistake was not discovered until it was too late to correct it in this edition.

What does fig. 139 represent? Explain the figure. Explain, by the figure, the situation of the earth on the 21st of June. What causes day and night? To what part of the earth is it day? To what part is it night? To what is the length of the day in proportion? When are the days the longest? Why? When are they the shortest? Why?

in that circle. As the whole of the Arctic Circle is within the line of perpetual light, no part of that circle will be turned from the sun while the earth turns on its axis. To all places, therefore, within the Arctic Circle, it will be constant day.

On the 22d of September, when the earth is at C, its axis is neither inclined *to*, nor *from* the sun, but is sideways; and, of course, while one half of the earth, from pole to pole, is enlightened, the other half is in darkness, as would be the case if its axis were perpendicular to the plane of its orbit; and it is this which causes the days and nights, of this season of the year, to be of equal length.

On the 23d of December, the earth has progressed in its orbit to B, which causes the whole space within the northern polar circle to be continually in darkness, and more of that part of the earth north of the equator to be in the shade than in the light of the sun. Hence, on the 21st of December, at all places north of the equator, the days are shorter than the nights, and at all places south of the equator, the days are longer than the nights. Hence, also, within the Arctic Circle it is uninterrupted night, the sun not shining at all; and within the Antarctic Circle it is uninterrupted day, the sun shining all the time.

On the 20th of March, the earth has advanced still further, and is at A, which causes its axis, and the length of the days and nights to be the same as on the 20th of September.*

From the explanation of figure 139, it appears that there are two parts of its orbit in which the days and nights are equal all over the earth. These points are in the sign of Aries and Libra, which are therefore called the equinoxes. Aries is the vernal (or spring) equinox, and Libra the autumnal equinox.

There are also two other points called solstices, because the sun appears to *stand* at the *same height* in the heavens, in the middle of the day, for several days. These points are in the signs Cancer and Capricorn. Cancer is called the summer solstice, and Capricorn the winter solstice.

* As the difference in the length of the days and the nights, and the change of the seasons, &c. on the earth, is caused by the inclination of the earth's axis, it follows that all the planets, whose axes are inclined, must experience the same vicissitude; and that it must be in proportion to the degree of the inclination of their axes. As the axis of the planet Jupiter is nearly perpendicular to its orbit, it follows that there can be little variation in the length of the days, and little change in the seasons of that planet.

There can be little doubt that the sun, the planets, stars, &c. are all of them inhabited; and although it may be thought that some of them, on account of their immense distance from the sun, experience a great want of light and heat, while others are so near, and the heat, consequently, so great that water cannot remain on them in a fluid state, yet, as we see, even on our own earth, that creatures of different nature live in different elements, as, for instance, fishes in water, animals in air, &c. creative wisdom could, undoubtedly, adapt the being to its situation, and with as little exertion of power, form a race whose nature should be adapted to the nearest, or the most remote of the heavenly bodies, as was required to adapt the fowls to the air, or the fishes to the sea.

Explain by the figure the situation of the earth on the 22d of September. On the 23d of December. On the 20th of March. What follows from the changes on the earth, caused by the inclination of the earth's axis? In what proportion are these changes? What is said of the axis of the planet Jupiter? Is it supposed that the sun, planets and stars are inhabited? What is shown by fig. 139? Where are these points? What are they called? Which is the vernal equinox? Which the autumnal? What other two points are there? Why are they called solstices? Where are these points? Which is the summer solstice? Which the winter?

467. The sun is a spherical body, situated near the centre of gravity, of the system of planets of which our earth is one. Its diameter is 877,547 English miles; which is equal to 100 diameters of the earth; and, therefore, his cubic magnitude must exceed that of the earth one million of times. It revolves around its axis in 25 days and 10 hours. This has been ascertained by means of several dark spots which have been seen with telescopes on its surface.

Dr. Herschel supposed the greater number of spots on the sun to be mountains; some of which he estimated to be 300 miles in height.

It is probable that the sun, like all the other heavenly bodies (excepting perhaps comets) is inhabited by beings whose nature is adapted to their peculiar circumstances.

Although, by some, the sun is supposed to be an immense ball of fire, on account of the effects produced at the distance of ninety-five millions of miles, yet many facts show that heat is produced by the sun's rays, only when they act on a suitable medium. Thus, snow and ice remain during the year, on the tops of the highest mountains, even in climates where the cold of our winters is never known.

It is supposed, by some astronomers, that the sun and planets have a general motion with relation to the fixed stars; and that their motion is at the rate of the earth's motion in its orbit. But at this rate, if the distance of the stars is two hundred thousand times that of the diameter of the earth's orbit, they would be sixty thousand years in moving over the distance of the nearest fixed star.

The zodiacal light is a singular phenomenon, accompanying the sun. It is a faint light which often appears to stream up from the sun a little after sunset and before sunrise. It appears nearly in the form of a cone, its sides being somewhat curved, and generally but ill defined. It extends often from 50° to 100° in the heavens, and always nearly in the direction of the plane of the ecliptic. It is most distinct about the beginning of March; but is constantly visible in the torrid zone. The cause of this phenomenon is not known.

In almanacs, the sun is usually represented by a small circle, with the face of a man in it, thus: 

468. Mercury is the nearest planet to the sun, and is seldom seen; because his vicinity to the sun occasions his being lost in the brilliancy of the sun's rays.

The heat of this planet is so great that water cannot exist there, except in a state of vapor; and metals would be melted. The in-

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467. What is said of the sun? What is its diameter? How much does its cubic magnitude exceed that of the earth? How long is it in performing its revolution around its axis? How has this been ascertained? What did Dr. Herschel suppose these spots to be? What is supposed by some astronomers of a general motion of the sun and planets with relation to the fixed stars? What is the Zodiacal light? At what time is it most distinct? Where is it constantly visible? 468. What planet is nearest to the sun? Why is it seldom seen? What is said of the heat of this planet?

tenseness of the sun's heat, which is in the same proportion as its light, is seven times greater in Mercury than on the earth; so that water there would be carried off in the shape of steam; for, by experiments made with a thermometer, it appears that a heat seven times greater than that of the sun's beams in summer, will make water boil.

Mercury, although in appearance only a small star, emits a bright white light, by which it may be recognized when seen. It appears a little before the sun rises, and again a little after sunset, but is never to be seen longer than one hour and fifty minutes after sunset; nor longer than that time before the sun rises.

When viewed through a good telescope, Mercury appears with all the various phases, or increase and decrease of light with which we view the moon; except that it never appears quite full, because its enlightened side is turned directly towards the earth, only when the planet is so near the sun as to be lost to our sight in its beams. Like that of the moon, the crescent or enlightened side of Mercury is always toward the sun. As no spots are commonly visible on the disk, the time of its rotation on its axis is unknown.

469. Venus,* the second planet in order from the sun, is the nearest to the earth, and on that account appears to be the largest and most beautiful of all the planets. During a part of the year it rises before the sun, and it is then called the morning star; during another part of the year it rises after the sun and it is then called the evening star. The heat and light at Venus are nearly double what they are at the earth.

As the orbits of Mercury and Venus are both within that of the earth, neither of those planets can ever appear at a greater distance than 90 degress, or a quarter of a circle from the sun.

These two planets sometimes pass directly between the sun and the earth. As their illuminated surface is toward the sun, their dark side is presented to the earth, and they appear like dark spots on the sun's disk. This is called the transit of those planets.

Venus, like Mercury, presents to us all the appearances of increase and decrease of light common to the moon. Spots are also sometimes seen on its surface, like those on the sun. By reason of

* By the ancient Poets, Venus was called *Phosphor*, or *Lucifer*, when it appeared to the west of the sun, at which time it is morning star, and ushers in the light or day; and Hesperus or Vesper, when eastward of the sun, or evening star.

How much greater is the sun's heat in Mercury than on the earth? In what form does water exist in Mercury? How can Mercury be recognized when seen? At what time does it appear? How does Mercury appear when viewed through a telescope? 469. What planet is nearest to the earth? When is Venus called the morning star? When is it called the evening star? How much greater are the heat and light at Venus than that at the earth? What name was given by the ancient poets, to Venus, when morning star? What, when evening star? What is the greatest distance at which the planets, Mercury and Venus, can ever appear from the sun? Why? What is meant by the transit of these planets? What is said of the different appearances which Venus presents?

the great brilliancy of this planet it may sometimes be seen even in the day time, by the naked eye.* In the absence of the moon it will cast a shadow behind an opake body.

470. The earth is the next planet, in the solar system, to Venus. It is not a perfect sphere, but its figure is that of an *oblate spheroid*, the equatorial diameter being about 34 miles longer than its polar diameter. It is attended by one moon, the diameter of which is about two thousand miles. Its mean distance from the earth is about 240 thousand miles, and it turns on its axis in precisely the same time that it performs its revolution round the earth; namely, in 29 days and a half. Hence, it appears that the moon always presents the same side to the earth. The earth, when viewed from the moon, exhibits precisely the same phases that the moon does to us, but in opposite order. When the moon is full to us, the earth will be dark to the inhabitants of the moon; and when the moon is dark to us, the earth will be full to them. The earth appears to them about 13 times larger than the moon does to us. As the moon, however, always presents the same side to the earth, there is one half of the moon which we never see, and which cannot see the earth.

471. Next to the earth is the planet Mars. It is conspicuous for its fiery red appearance; which is supposed to be caused by a very dense atmosphere, visible through a telescope; so that when this planet approaches any of the fixed stars, they change their color, grow dim, and often become totally invisible. The degree of heat and light at Mars is less than half of that received by the earth.

472. The four small planets or asteroids, Vesta, Juno, Ceres and Pallas, have all been discovered within

* The reason why we cannot see the stars and planets in the day time, is, that their light is so faint, compared with the light of the sun reflected by our atmosphere.

Why can we not see the planets and stars in the day time? 470. What planet is next to Venus? What is the form of the earth? How much larger is its equatorial diameter than its polar? How many moons has the earth? What is the diameter of the moon? What is its distance from the earth? What is the length of a day at the moon? How long is it in performing its revolution around the earth? What phases does the earth, when viewed from the moon, exhibit? How much larger does the earth appear than the moon? 471. What planet is next to the earth? What renders it conspicuous? What is supposed to cause this appearance? How much more light and heat does the earth enjoy than Mars? 472. When were the asteroids discovered?

the present century. Vesta was discovered by Dr. Olbers, of Bremen, in 1807. Its light is pure and white. Juno, by Mr. Harding, near Bremen, in 1804. Its color is red, and its atmosphere appears cloudy. Pallas was discovered by Dr. Olbers in 1802. It appears to have a dense cloudy atmosphere. Ceres was discovered at Palermo, in Sicily, by Piazzi, in 1801. It is of a ruddy color. All of these small planets undergo various changes in appearance and size, so that their real magnitude is not ascertained with any certainty; and but little is known of them.*

473. Jupiter is the largest planet of the solar system, and it is the most brilliant, except Venus. The heat and light at Jupiter is about 25 times less than that at the earth. This planet is attended by four moons, or satellites; the shadows of some of which are occasionally visible upon his surface.

The distance of those satellites from the planet are two, four, six and twelve hundred thousand miles, *nearly*.

The nearest revolves around the planet in less than two days; the next in less than four days; the third in less than eight days; and the fourth in *about* sixteen days.

These four moons must afford considerable light to the inhabitants of the planet; for the nearest appears to them four times the size of our moon; the second about the same size; the third somewhat less, and the fourth about one third the diameter of our moon.

As the axis of Jupiter is nearly perpendicular to its orbit, it has no sensible change of seasons.

The satellites of Jupiter often pass behind the body of the plan-

* It is a remarkable fact, that certain irregularities, observed in the motions of the old planets, induced some astronomers to suppose that a planet existed between the orbits of Mars and Jupiter; a supposition that arose long previous to the discovery of the four new planets just noticed. The opinion has been advanced, that these four small bodies originally composed one larger one, which, by some unknown force or convulsion, burst asunder. This opinion is maintained with much ingenuity and plausibility by Dr. Brewster, in the Edinburgh Encyclopedia, *Art.* Astronomy. Dr. Brewster further supposes, that the bursting of this planet may have occasioned the phenomena of the meteoric stones; that is, stones which have fallen on the earth from the atmosphere.

By whom, and in what year was Vesta discovered? What is the color of its light? By whom and when was Juno discovered? What is the color of its light? When was Pallas discovered? By whom? What is said of its atmosphere? When and by whom was Ceres discovered? What is its color? What is said in the note with regard to these planets? 473. Which of the planets is the largest? How much more light and heat does the earth enjoy than Jupiter? How many moons has this planet? What is the distance of these moons from the planet? In what time do they perform their revolutions around the planet? How does the size of these moons compare with that of ours? Why has Jupiter no sensible variety of seasons?

et, and also into its shadow, and are eclipsed. These eclipses are of use in ascertaining the longitude of places on the earth. By these eclipses also, it has been ascertained that light is about 8 minutes in coming from the sun to the earth. For, an eclipse of one of these satellites appears to us to take place 16 minutes sooner, when the earth is in that part of its orbit nearest Jupiter, than when in the part farthest from the planet. Hence, light is sixteen minutes in crossing the earth's orbit, and, of course, half of that time, or 8 minutes, in coming from the sun to the earth.

When viewed through a telescope, several belts or bands are distinctly seen, sometimes extending across his disk, and sometimes interrupted and broken. They differ in distance, position, and number. They are generally dark; but white ones have been seen.

On account of the immense distance of Jupiter from the sun, and also from Mercury, Venus, the Earth and Mars, observers on Jupiter, with eyes like ours, can never see either of the above named planets, because they would always be immersed in the sun's rays.

474. Saturn is the second in size and the last but one in distance from the sun. The degree of heat and light at this planet is eighty times less than that at the earth.

Saturn is distinguished from the other planets by being encompassed by two large luminous rings, one exactly without or beyond the other. They reflect the sun's light in the same manner as his moons. They are entirely detached from each other and from the body of the planet. They turn on the same axis with the planet, and in nearly the same time.* The edge of these rings is constantly at right angles with the axis of the planet. Stars are sometimes seen between the rings, and also between the inner ring and the body of the planet. The breadth of the two rings is about the same as their distance from the planet, namely, 21,000 miles. As they cast shadows on the planet, Dr. Herschel thinks them solid.

The surface of Saturn is sometimes diversified, like that of Jupiter, with spots and belts. Saturn has seven satellites, or moons, revolving around him at different distances and in various times, from less than one to eighty days.

Saturn may be known by his pale and steady light. The seven moons of Saturn, all, except one, revolve at different distances around the outer edge of his rings. Dr. Herschel saw them mov-

* These rings move together around the planet, but are about *thirteen minutes* longer in performing their revolution about him, than Saturn is in revolving about his axis.

Of what use are the eclipses of Jupiter's moons? How long is light in coming from the sun to the earth? How has this been ascertained? How does Jupiter appear when viewed through a telescope? 474. How does Saturn compare in size with the other planets? How is Saturn distinguished from the other planets? What is said of these rings? How much longer are these rings in performing their revolution around the planet than the planet is in performing its revolution on its axis? What is the breadth of these rings? What is said of the surface of Saturn? How many moons has Saturn? How may Saturn be known? What is said of the moons of Saturn?

ing along it, like bright beads on a white string. They do not often suffer eclipse by passing into the shadow of the planet, because the ring is generally in an oblique direction.

475. Herschel, the third in size, is the most remote of all the planets. It is scarcely visible to the naked eye. The light and heat at Herschel are about 360 times less than that at the earth.

This planet was formerly considered a small star, but Dr. Herschel, in 1781, discovered from its motion that it is a planet. He modestly gave it the name of Georgium sidus, or the Georgium star, in honor of his King, George the Third. On the continent of Europe it is called *Uranus.*

Herschel is attended by six moons, or satellites; all of which were discovered by Dr. Herschel, and all of them revolve in orbits nearly perpendicular to that of the planet. Their motion is *apparently* retrograde; but this is probably an optical illusion, arising from the difficulty of ascertaining which part of their orbit inclines towards the earth, and which declines from it.*

It is a singular circumstance that, before the discovery of Herschel, some disturbances and deviations were observed by astronomers in the motions of Jupiter and Saturn, which they could account for only on the supposition that these two planets were influenced by the attraction of some more remote and undiscovered planet. The discovery of Herschel completely verified their opinions, and shows the extreme nicety with which astronomers observe the motions of the planets.

476. The word comet is derived from a Greek word, which means *hair;* and this name is given to a numer-

* It appears to be a general law of satellites, or moons, that *they turn on their axes in the same time in which they revolve around their primaries.* On this account, the inhabitants of secondary planets observe some singular appearances, which the inhabitants of primary planets do not. Those who dwell on the side of a secondary planet next to the primary will always see that primary; while those who live on the opposite side will never see it. Those who always see the primary, will see it constantly in very nearly the same place. For example, those who dwell near the edge of the moon's disk will always see the earth near the horizon, and those in or near the centre will always see it directly or nearly over head. Those who dwell in the moon's south limb will see the earth to the northward; those in the north limb will see it to the southward; those in the east limb will see it to the westward; while those in the west limb will see it to the eastward; and all will see it nearer the horizon in proportion to their own distance from the centre of the moon's disk. Similar appearances are exhibited to the inhabitants of all secondary planets.

Why are they not often eclipsed? 475. How does Herschel compare in size with the other planets? How does the light and heat at Herschel compare with that of the earth? By whom was this planet discovered? What name did he give it? How many moons has Herschel? By whom were they discovered? How are their orbits situated with regard to that of the planet? What is said of their motion? What appears to be a general law of satellites? What follows from this with regard to the appearances which the inhabitants of the secondary planets must observe? 476. What is the meaning of the word comet?

ous class of bodies which occasionally visit, and appear to belong to the solar system. These bodies appear to consist of a nucleus, attended with a lucid haze, sometimes resembling flowing hair; from whence the name is derived. Some comets seem to consist wholly of this hazy or hairy appearance, which is frequently called *the tail* of the comet.

In ancient times the appearance of comets was regarded with superstitious fear, in the belief that they were the forerunners of some direful calamity. These fears have now been banished, and the comet is viewed as a constituent member of the system, governed by the same harmonious and unchanging laws which regulate and control all the other heavenly bodies.*

Comets in moving, describe long, narrow ovals. They approach very near the sun in one of the narrow ends of these ovals; and when a comet is in the other, or opposite end of its orbit, its distance from the sun is incalculably great.

The extreme nearness of approach to the sun, gives to the comet, when in perihelion, a swiftness of motion prodigiously great. Newton calculated the velocity of the comet of 1680, to be 880,000 miles an hour. This comet was remarkable for its near approach to the sun; being no further than 580,000 miles from it; which is but little more than half the sun's diameter. Brydone calculated, that the velocity of a comet which he observed at Palermo in 1770, was at the rate of two millions and a half of miles in an hour.

The luminous stream, or tail of a comet, follows it as it approaches the sun, and goes before it when the comet recedes from the sun. Newton and some other astronomers considered the tails of comets to be vapors, produced by the excessive heat of the sun. Of whatever substance they may be, it is certain that it is very *rare*, because the stars may be distinctly seen through it.

* The number of comets that have occasionally appeared within the limits of the solar system, is variously stated from 350 to 500. The paths or orbits of about 98 of these have been calculated from observation of the times at which they most nearly approached the sun; their distance from it and from the earth at those times; the direction of their movements, whether from east to west, or from west to east; and the places in the starry sphere at which their orbits crossed that of the earth, and their inclination to it. The result is that of these 98, 24 passed *between* the Sun and Mercury, 33 passed between Mercury and Venus, 21 between Venus and the Earth, 16 between the Earth and Mars, 3 between Mars and Ceres, and 1 between Ceres and Jupiter; that 50 of these comets moved from east to west; that their orbits were inclined at every possible angle to that of the earth; the greater part of them ascended above the orbit of the earth, when very near the sun; and some were observed to dash down from the upper regions of space, and after turning round the sun to mount again.

To what class of bodies is this name given? Of what do these bodies appear to consist? What is the number of comets that have occasionally appeared? What discoveries have been made concerning 98 of them? What is the result? What is the form of the orbits of comets? What is said of the motion of comets when in perihelion? What did Newton calculate the velocity of the comet in 1680, to be in an hour? For what was this comet remarkable? What is said of the luminous stream of a comet as it approaches and recedes from the sun? What did Newton, and some other astronomers, consider the tails of comets to be?

The tails of comets differ very greatly in length, and some are attended apparently by only a small cloudy light, while the length of the tail of others has been estimated, at from 50, to 80 millions of miles.*

477. The stars are classed into six magnitudes; the largest are of the first magnitude, and the smallest that can be seen by the naked eye, are of the sixth. Those stars which can be seen only by means of telescopes, are called telescopic stars.

The distance of the fixed stars cannot be determined, because we have no means of ascertaining the distance of any body, which exceeds 200 thousand times that of the earth. As none of the stars come within that limit, we cannot determine their real distance. It is generally supposed, that a part, if not all of the difference in their apparent magnitudes, is owing to the difference in their distance, the smallest being farthest off.

Although the stars generally appear fixed, they all have motion; but their distance being so immensely great, a rapid motion would not perceptibly change their relative situation in two or three thousand years. Some have been noticed alternately to appear and disappear; several that were mentioned by ancient astronomers, are not now to be seen; and some are now observed, which were unknown to the ancients.

* It has been argued that comets consist of very little solid substance, because, although they sometimes approach very near to the other heavenly bodies, they appear to exert no sensible attractive force upon those bodies. It is said, that in 1454 the moon was eclipsed by a comet. The comet, must, therefore, have been very near the earth; (less than 240 thousand miles,) yet it produced no sensible effect on the earth, or the moon, for it did not cause them to make any perceptible deviation from their accustomed paths round the sun. It has been ascertained that comets are disturbed by the gravitating power of the planets, but it does not appear that the planets are in like manner affected by comets.

Many comets escape observation, because they traverse that part of the heavens only which is above the horizon in the day time. They are, therefore, lost in the brilliance of the sun, and can be seen only when a *total* eclipse of the sun takes place. Seneca, 60 years before the Christian era, states that a large comet was actually observed very near the sun, during an eclipse.

Dr. Halley and Professor Encke and Biela are the first astronomers that ever successfully predicted the return of a comet. The periodical time of Halley's comet is *about* 76 years. It appeared last in the fall of 1835,—that of Encke is about 1200 days—that of Biela about 6 3-4 years. This last comet appeared in 1832, its next appearance will be in 1838.

The comet of 1758, the return of which was predicted by Dr. Halley, was looked upon with great interest by astronomers, *because its return was predicted.* But four revolutions before, in 1456, it was looked upon with the utmost horror. Its long tail spread consternation over all Europe, already terrified by the rapid success of the Turkish arms. Pope Callixtus, on this occasion, ordered a prayer, in which both the comet and the Turks were included in one anathema.

What is said in the note with regard to comets? Who were the first astronomers that successfully predicted the return of a comet? What is the periodical time of Halley's comet? Of Encke's? Of Biela's? 477. Into how many magnitudes are the stars classed? Of what magnitude are the largest? Of what are the smallest? What are telescopic stars? Why cannot the distance of the fixed stars be determined? To what is the difference in their apparent magnitudes supposed to be owing? Have the stars any motion?

Many stars which appear single to the naked eye, when viewed through powerful telescopes appear double, treble, and even quadruple. Some are subject to variation in their apparent magnitude; at one time being of the second, or third, and, at another, of the fifth or sixth magnitude.

478. The Galaxy, or milky way, is the name given to a remarkably light broad zone, visible in the heavens, passing from north-east to southwest. It is supposed to consist of an immense number of stars, which, from their apparent nearness, cannot be distinguished from each other.

Dr. Herschel saw, in the course of a quarter of an hour, the astonishing number of 116,000 stars pass through the field of his telescope, while it was directed to the milky way.

479. The ancients, in reducing astronomy to a science, formed the stars into *clusters*, or *constellations*,* to which they gave particular names.

The number of constellations among the ancients was about fifty. The moderns have added about fifty more.†

On a celestial globe, the largest star in each constellation is usually designated by the first letter of the Greek alphabet; and the next largest by the second, &c. When the Greek alphabet is exhausted, the English alphabet, and then numbers are used.

480. The stars, and other heavenly bodies are never seen in their true situation, because the motion of light is *progressive;* and, during the time that light is *coming to* the earth, the earth is constantly in motion. In order, therefore, to see a star, the telescope must be turned somewhat *before* the star, in the direction in which the earth moves. [*See Resultant Motion, page* 43.]

* The names of the signs of the zodiac have already been given. (*See page* 193.) It remains to be observed that each constellation is about 30 degrees, or a sign, eastward of the sign of the same name. For example, the constellation Aries is 30° eastward of the sign Aries, and the constellation Taurus, 30° eastward of the sign Taurus, and so on. Thus the sign Aries lies in the constellation Pisces; the sign Taurus in the constellation Aries; the sign Gemini in the constellation Taurus, and so on. Hence the importance of distinguishing between the *signs* of the zodiac and the *constellations* of the zodiac. The cause of the difference is the precession of the equinoxes. [*See note on page* 193 *and page* 220.]

† Our observations of the stars and nebulæ are confined principally to those of the northern hemisphere. Of the constellations near the south pole, we know but little.

478. What is the galaxy? Of what is it supposed to consist? 479. How did the ancients divide the stars? What was the number of constellations among the ancients? How many have been added by the ancients? How are the stars designated on the celestial globe? What is the situation of each constellation now? Illustrate this. What is the cause of this difference? 480. Why do we not see the stars, and other heavenly bodies, in their true situation? How can a star be seen in its true situation?

Hence, a ray of light passing through the centre of the telescope, to the observer's eye, does not coincide with a direct line from his eye to the star, but makes an angle with it; and this is termed the *aberration of ligh'.**

481. On account of the daily rotation of the earth on its axis, the whole sphere of the fixed stars, &c. appears to move round the earth every twenty-four hours from east to west. To the inhabitants of the northern hemisphere, the immovable point, on which the whole seems to turn, is the *Pole Star*. To the inhabitants of the southern hemisphere, there is another, and a corresponding point in the heavens.

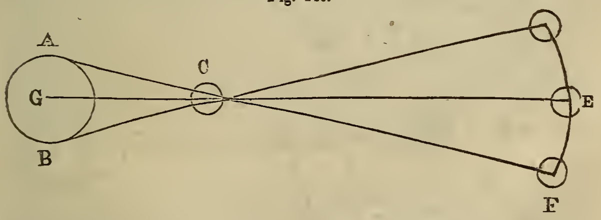
Certain of the stars surrounding the south pole, never set to us, These are included in a circle parallel with the equator, and in every part equally distant from the north pole star. This circle is called the circle of *perpetual apparition*. Others never rise to us; these are included in a circle equally distant from the south pole; and this is called the circle of *perpetual occultation*.

Some of the constellations of the southern hemisphere, are represented as inimitably beautiful, particularly *the cross*.

482. The parallax of a heavenly body is the difference between the *true* and the *apparent* situation of the body.

Illustration. In fig. 140, A G B represent the earth, and C the moon. To a spectator at A, the moon would appear at F; while to another at B, the the moon would appear at D; but to a

Fig. 140.



third spectator at G, the centre of the earth, the moon would appear at E, which is the true situation. The distance from F to E is the parallax of the moon when viewed from A, and the distance from E to D is the parallax when viewed from B.

* In determining the true place of *any* of the celestial bodies, the refractive power of the atmosphere must always be taken into consideration. This property of the atmosphere adds to the length of the days, by causing the sun to appear *before* it has actually risen, and by detaining its *appearance* after it has actually set.

What is meant by the aberration of light? What is necessary to be taken into consideration in determining the true place of the celestial bodies? What effect has this property of the atmosphere on the length of the days? 482. What is the parallax of a heavenly body? Explain fig. 140. What appears from this?

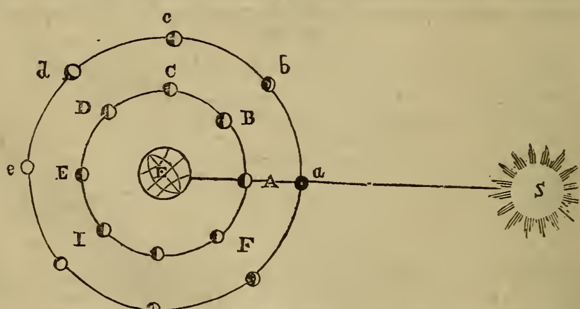
From this it appears, that the situation of the heavenly bodies must always be calculated from the centre of the earth; and the observer must always know the distance between the place of his observation, and the centre of the earth, in order to make the necessary calculations, to determine the true situation of the body. Allowance also must be made for refraction. [*See note to No.* 354.]

483. The moon is a secondary planet, revolving about the earth, in about $29\frac{1}{2}$ days. Its distance from the earth is about 240,000 miles. It turns on its axis in precisely the same time that it performs its revolution about the earth. Consequently it always presents the same side to the earth.

The most obvious fact in relation to the moon, is that its disk is constantly changing its appearance, sometimes only a semicircular edge being illuminated, while the rest is dark; at another time, the whole surface appearing resplendent. This is caused by the relative position of the moon with regard to the sun and the earth. The moon is an opaque body, and shines only by the light of the sun. When, therefore, the moon is between the earth and the sun, it presents its dark side to the earth; while the side presented to the sun, and on which the sun shines, is invisible to the earth. But when the earth is between the sun and the moon, the illuminated side of the moon is visible at the earth.

Illustration. In Fig. 141, let S be the sun, E the earth, and A B C D the moon in different parts of her orbit. When the

Fig. 141.



moon is at A, its dark side will be towards the earth, its illuminated part being always towards the sun. Hence the moon will appear to us as represented at *a*. But when it has advanced in

What allowance must also be made? 483. Is the moon a primary or secondary planet? How long is it in performing its revolution about the earth? What is its distance from the earth? What is the most obvious fact in relation to the moon? How is this caused? What kind of a body is the moon? By what light does it shine?

its orbit, and come to B, a small part of its illuminated side comes in sight it appears as represented at *b*, and is said to be *horned.* When it has come to C, one half its illuminated side is visible, and it appears as at *c*. At C, and in the opposite point of its orbit, the moon is said to be in *quadrature.* At D its appearance is as represented at *d*, and it is said to be *gibbous.* At E all its illuminated side is toward us, and we have a full moon. During the other half of its revolution, less and less of its illuminated side is seen, till it again becomes invisible at A.*

The mean difference in the rising of the moon, caused by its daily motion, is a little less than an hour. But on account of the different angles formed with the horizon by different parts of the ecliptic, it happens that for six or eight nights near the full moons of September and October, the moon rises nearly as soon as the sun is set. As this is a great convenience to the husbandman and the hunter, inasmuch as it affords them light to continue their occupation, and, as it were, lengthens out their day, the first is called the *harvest* moon, the second the *hunter's* moon. These moons are always most beneficial when the moon's ascending node is in or near *Aries.*†

484. An eclipse is a total or partial obscuration of one heavenly body by the intervention of another.‡

* The following signs are used in our common almanacs to denote the different positions and phases of the moon. ☽ or ☽ denotes the moon in the *first* quadrature; that is, the quadrature between change and full; ☾ or ☾ denotes the moon in the *last* quadrature; that is, the quadrature between full and change; ○ denotes new moon; ● denotes full moon.

When viewed through a telescope, the surface of the moon appears wonderfully diversified. Large dark spots, supposed to be excavations or valleys, are visible to the eye; some parts also, appear more lucid than the general surface. These are ascertained to be mountains, by the shadows which they cast. Maps of the moon's surface have been drawn; on which most of these valleys and mountains are delineated, and names are given to them. Some of these excavations are thought to be 4 miles deep and 40 wide. A high ridge generally surrounds them, and often a mountain rises in the centre. These immense depressions probably very much resemble what would be the appearance of the earth at the moon, were all the seas and lakes dried up. Some of the mountains are supposed to be volcanic.

† The reader who wishes a simple and clear illustration of the causes which produce the harvest moon is referred to Wilkins' Astronomy, page 69.

‡ The situation of the earth with regard to the moon, or rather of the moon with regard to the earth, occasions eclipses both of the sun and moon. Those of the sun take place when the moon, passing between the sun and earth, intercepts his rays. Those of the moon take place when the earth, coming between the sun and moon, deprive the moon of his light. Hence, an eclipse of the sun can take place only when the moon changes, and an eclipse of the moon only when the moon fulls; for *at the time of an eclipse*, either of the sun or moon, *the sun, earth, and moon must be in the same straight line.*

If the moon went around the earth in the same plane in which the earth goes

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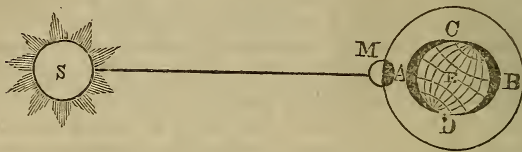
How does the moon appear when viewed through a telescope? What causes the difference in the rising of the moon? What is the mean difference in the rising of the moon? What is the harvest moon? What is the hunter's moon? When are the moons always the most beneficial? 484. What is an eclipse? When does an eclipse of the sun take place? When does an eclipse of the moon take place? What is necessary at the time of an eclipse?

485. The tides are the regular rising and falling of the water of the ocean twice in about 25 hours. They are occasioned by the attraction of the moon; but are affected by that of the sun also.

Fig. 142.



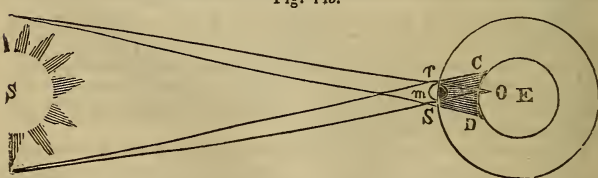
Let M, in the above figure, be the moon revolving in its orbit; E, the earth covered with water. The moon, attracting the earth, affects the solid parts of it, as if its whole weight were in a point at

around the sun, that is, in the ecliptic, it is plain that the sun would be eclipsed at every new moon; and the moon would be eclipsed at every full. For at each of these times, these three bodies would be in the same straight line. But the moon's orbit does not coincide with the ecliptic, but is inclined to it at an angle of about 5° 20′. Hence, since the apparent diameter of the sun is but about 1-2 a degree, and that of the moon about the same, no eclipse will take place at new or full moon, unless the moon be within 1 2 a degree of the ecliptic, that is, in or near one of its nodes. It is found that if the moon be within 16 1-2° of a node at time of change, it will be so near the ecliptic, that the sun will be more or less eclipsed; if within 12° at time of full, the moon will be more or less eclipsed.

It is obvious that the moon will be oftener within 16 1-2° of a node at the time of change, than within 12° at the time of full; consequently there will be more eclipses of the sun than of the moon in a course of years. As the nodes commonly come between the sun and earth but twice in a year, and the moon's orbit contains 360°, of which 16 1-2°, the *limit* of solar eclipses, and 21°, the *limit* of lunar eclipses, are but small portions, it is plain there must be many new and full moons without any eclipses.

Although there are more eclipses of the sun than of the moon, yet more eclipses of the moon will be visible at a particular place, as Boston, in a course of years, than of the sun. Since the sun is very much larger than either the earth or moon, the shadow of these bodies must always terminate in a point; that is, it must always be a cone. In Fig. 143, let S be the sun, *m* the moon, and E the earth. The

Fig. 143.



485. What are tides? By what are they occasioned? Explain fig. 143. How often would there be an eclipse, if the moon went round the earth in the same plane in which the earth goes round the sun? Why? What is the inclination of the moon's orbit to the ecliptic? What is the apparent diameter of the sun and moon? What follows from this? When is the sun eclipsed? When the moon? Does an eclipse happen every time there is a full or new moon? What must the shadows of these bodies always be? Why? Explain fig. 143.

or near the centre E. But the waters at A, being nearer the moon than the point E, are more strongly attracted than the earth, at E, and are consequently drawn away from the earth, and raised up under the moon at A. The waters, on the opposite side at B, being further from the moon than the earth at E, are consequently less powerfully attracted than the earth, which is drawn from them, and they are raised at B. When the waters are raised at A and B, it is plain they must recede from the intermediate points C and D.

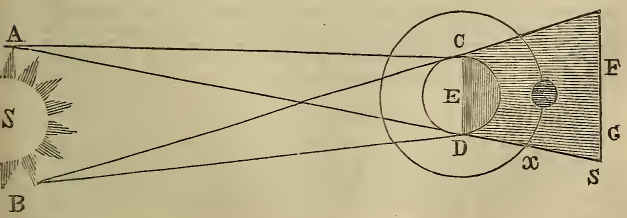
Thus any particular place as A, while passing from under the moon, till it comes under the moon again, has two tides. But the moon is constantly advancing in its orbit, so that the earth must a little more than complete its rotation, before the place A comes under the moon. This causes high water at any place about 50 minutes later each successive day.

sun constantly illuminates half the earth's surface, that is, a hemisphere; and consequently it is visible to all in this hemisphere. But the moon's shadow falls upon a part only of this hemisphere; and hence the sun appears eclipsed to a part only of those to whom it is visible. Sometimes, when the moon is at its greatest distance, its shadow, O *m*, terminates before it reaches the earth. In eclipses of this kind, to an inhabitant directly under the point O, the outermost edge of the sun's disk is seen, forming a bright ring round the moon; from which circumstance these eclipses are called *annular*, from *annulus*, a Latin word for ring.

Besides the dark shadow of the moon, *m* O, in which all the light of the sun is intercepted, (in which case the eclipse is called *total*,) there is another shadow, *r* C D S, distinct from the former, which is called the *penumbra*. Within this, only a part of the sun's rays are intercepted, and the eclipse is called *partial*. If a person could pass, during an eclipse of the sun from O to D, immediately on immerging from the dark shadow, O *m*, he would see a small part of the sun; and would continually see more and more till he arrived at D, where all shadow would cease, and the whole sun's disk be visible. Appearances would be similar if he went from O to C. Hence the penumbra is less and less dark, (because a less portion of the sun is eclipsed,) in proportion as the spectator is more remote from O, and nearer C or D. Though the penumbra is continually increasing in diameter according to its length, or the distance of the moon from the earth, still, under the most favorable circumstances, it falls on but about half of the illuminated hemisphere of the earth Hence, by half the inhabitants on this hemisphere, no eclipse will be seen.

Fig. 144 represents an eclipse of the moon. The instant the moon enters the earth's shadow at *x*, it is deprived of the sun's light, and is eclipsed to all in the unilluminated hemisphere of the earth. Hence, eclipses of the moon are visible to at least twice as many inhabitants as those of the sun can be; generally the pro-

Fig. 144.



When is an eclipse called annular? Explain by fig. 144 What is a penumbra? Why are eclipses of the moon visible to more inhabitants than those of the sun?

As the moon's orbit varies but little from the ecliptic, the moon is never more than 29° from the equator, and is generally much less. Hence the waters about the equator being nearer the moon, are more strongly attracted, and the tides are higher than towards the poles.

The sun attracts the waters as well as the moon. When the moon is at full or change, being in the same line of direction, it acts with the sun; that is, the sun and moon tend to raise the tides at the same place, as seen in the figure. The tides are then very high, and are called *spring* tides.

portion is much greater. Thus, the inhabitants at a particular place, as Boston, see more eclipses of the moon than of the sun.

The reason why a *lunar* eclipse is visible to all to whom the moon at the time is visible, and a *solar* one is not to all to whom the sun at the time is visible, may be seen from the nature of these eclipses. We speak of the sun's being eclipsed; but properly it is the earth which is eclipsed. No change takes place in the sun; if there were, it would be seen by all to whom the sun is visible. The sun continues to diffuse its beams as freely and uniformly at such times as at others. But these beams are intercepted, and the earth is eclipsed only where the moon's shadow falls, that is, on only a part of a hemisphere. In eclipses of the moon, that body ceases to receive light from the sun, and, consequently, ceases to reflect it to the earth. The moon undergoes a change in its appearance; and, consequently this change is visible at the same time to all to whom the moon is visible; that is, to a whole hemisphere of the earth.

The earth's shadow (like that of the moon) is encompassed by a penumbra, C R S D, which is faint at the edges towards R and S, but becomes darker towards F and G. The shadow of the earth is but little darker than the region of the penumbra next to it. Hence it is very difficult to determine the exact time when the moon passes from the penumbra into the shadow, and from the shadow into the penumbra; that is, when the eclipse begins and ends. But the beginning and ending of a solar eclipse may be determined instantaneously.

The diameters of the sun and moon are supposed to be divided into 12 equal parts, called *digits*. These bodies are said to have as many digits eclipsed as there are of those parts involved in darkness.

There must be an eclipse of the sun as often at least as one of the moon's nodes comes between the sun and the earth.

The greatest number of both solar and lunar eclipses that can take place during a year is seven. The usual number is four; two solar and two lunar.

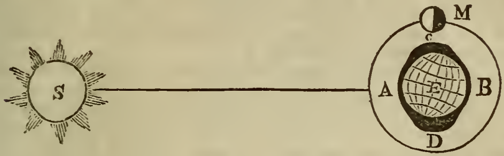
A total eclipse of the sun is a very remarkable phenomenon.

June 16, 1806, a very remarkable total eclipse took place at Boston. The day was clear, and nothing occurred to prevent accurate observation of this interesting phenomenon. Several stars were visible; the birds were greatly agitated; a gloom spread over the landscape, and an indescribable sensation of fear or dread pervaded the breasts of those, who gave themselves up to the simple effects of the phenomenon, without having their attention diverted by efforts of observation. The first gleam of light, contrasted with the previous darkness, seemed like the usual meridian day, and gave indescribable life and joy to the whole creation. A total eclipse of the sun can last but little more than three minutes. An annular eclipse of the sun is still more rare than a total one.

What is the distance of the moon from the equator? Where are the tides the highest? Why? How are spring tides caused? Why is a lunar eclipse visible to all to whom the moon is visible at the time? What is said of the earth's shadow? Explain by the figure? Into what are the diameters of the sun and moon supposed to be divided? How many digits are these bodies said to have eclipsed? How often must there be an eclipse of the sun? What is the greatest number, of both lunar and solar eclipses, that can take place during a year? What is the usual number? What is said of the eclipse of the sun in 1806?

But when the moon is in its quarters, as in figure 145, the sun and moon being in opposite directions, tend to raise tides at different

Fig. 145.



places; namely, the moon at C and D, and the sun at A and B. Tides, that are produced when the moon is in its quarters, are low, and are called *neap* tides.*

486. When time is calculated by the sun, it is called solar time, and the year a solar year; but when it is calculated by the stars,† it is called sidereal time, and the year a sidereal year. The sidereal year is 20 minutes and 24 seconds longer than the solar year.

A solar year‡ is measured from the time the earth sets out from a particular point in the ecliptic, as an equinox, or solstice, until it returns to the same point again. A sidereal year is measured by the time that the earth takes in making an entire revolution in its orbit;

*There are so many natural difficulties to the free progress of the tides, that the theory by which they are accounted for, is, in fact, and necessarily, the most imperfect of all the theories connected with astronomy. It is, however, indisputable that the moon has an effect upon the tides, although it is not equally felt in all places, owing to the indentations of the coast—the obstructions of islands, continents, &c., which prevent the free motion of the waters. In narrow rivers, the tides are frequently very high and sudden, from the resistance afforded by their banks to the free ingress of the water, whence what would otherwise be a tide becomes an accumulation. It has been constantly observed that the spring tides happen at the new and full moon, and the neap tides at the quarters. This circumstance is sufficient in itself to prove the connexion between the influence of the moon and the tides.

†The solar year consists of 365 days, 5 hours, 48 minutes, and 48 seconds, but our common reckoning gives 365 days only to the year. As the difference amounts to nearly a quarter of a day, every year, it is usual every fourth year to add a day. Every fourth year, the Romans reckoned the *6th of the calends of March, and the following day as one day*; which on that account they called bissextile, or twice the 6th day; whence we derive the name of bissextile, for the leap year, in which we give to February, for the same reason, 29 days every fourth year.

‡As it may be interesting, to those who have access to a celestial globe, to know how to find any particular star or constellation, the following directions are subjoined:—

There is always to be seen, on a clear night, a beautiful cluster of seven brilliant stars, which belong to the constellation "*Ursa Major*," or the Great Bear. Some have supposed that they will aptly represent a plough—others say that they

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How are neap tides caused? Explain fig. 145. When do spring tides happen? When, neap tides? 486. What is time called when calculated by the sun? What is sidereal time? How much longer is the sidereal year than the solar. How is a solar year measured. What is the length of a solar year? Why is a day added every fourth year, to the year? How is a sidereal year measured?

or, in other words, from the time that the sun takes to return in conjunction with any fixed star.

Every equinox, happens 50 seconds of a degree of the great circle, preceding the place of the equinox, 12 months before; and this is called the *precession of the equinoxes.* It is this circumstance which has caused the change in the situation of the constellations mentioned in pages 193 and 212.

The earth's diurnal motion on an inclined axis, together with its annual revolution in an elliptic orbit, occasions so much complication in its motion, as to produce many irregularities; therefore true equal time cannot be measured by the sun. A clock, which is always perfectly correct, will in some parts of the year be before the sun, and in other parts after it. There are but four periods in which the sun and a perfect clock will agree; these are the 15th of April, the 16th of June, the 23d of August, and the 24th of December.

The greatest difference between true and apparent time, amounts to between fifteen and sixteen minutes. Tables of equation are constructed for the purpose of pointing out and correcting these differences between solar time and equal or mean time, the denomination given by astronomers to true time.

are more like a waggon and horses—the four stars representing the body of the waggon, and the other three the horses. Hence, they are called by some *the plough*, and by others they are called *Charles' wain*, or *waggon.*

Fig. 146.

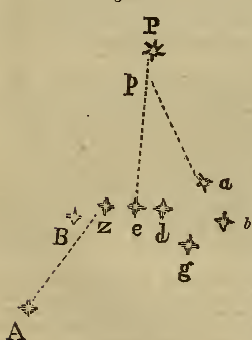


Fig. 146 represents these seven stars; *a b g d* represent the four, and *e z* B the other three stars. Perhaps they may more properly be called a large dipper, of which *e z* B represent the handle. If a line be drawn through the stars *b* and *a* and carried upwards, it will pass a little to the left and nearly touch a star represented in the figure by P. This is the polar star, or the North pole star, and the stars *b* and *a*, which appear to point to it, are called *the pointers*, because they appear to point to the polar star.

The polar star shines with a steady and rather dead kind of light. It always appears in the same position; and the north pole of the earth always points to it *at all seasons of the year.* The other stars seem to move round it as a centre. As this star is always in the north, the cardinal points may at any time be found by starlight.

By these stars we can also find any other star or constellation.

Thus, if we conceive a line drawn from the star z, leaving B a little to the left, it will pass through the very brilliant star A. By looking on a celestial globe for the star z, and supposing the line drawn on the globe, as we conceive it done on the heavens, we shall find the star and its name, which is Arcturus.

Conceiving another line, drawn through *g* and *b*, and extended some distance to to the right, it will pass just above another very brilliant star. On referring to the globe we find it to be Capella, or the goat.

In this manner the student may become acquainted with the appearance of the whole heavens.

What is the precession of the equinoxes? What change has this circumstance caused with regard to the situation of the constellations? Can true, equal time be measured by the sun? Why? At what periods of the year do the sun and a perfect clock agree? What is the greatest difference between true and apparent time.

Many of the foregoing facts, with some others relating to the bodies which compose the solar system, are arranged in the following tables; useful for reference, but not necessary to be learned. The numbers in these Tables differ, in some respects, from those contained in the body of the work, as they were taken from a different authority.

TABLE I.—*Of the Sun and Primary Planets.*

	Dist. in mill.	Time of revolving round the Sun.	Time of turning on their Axis.	Diameter in miles.	The earth being 1. Bulk.	Heat and Light.	Density.	Greatest distance from the ecliptic.	Hourly motion, in miles.	Eccentricity Mean Dist. 1
SUN	**	* *	25.5 d.	883.217	1380000	* *	$\frac{1}{4}$	* *	* *	* *
Mercury	37	87.97.d.	24. h.	3123	$\frac{1}{15}$	6.68	2	7°40′	110.000	0.205
Venus	68	224.7"	23.36h.	7702	$\frac{8}{9}$	1.91	$1\frac{1}{4}$	3°23′	84.000	0.007
Earth	93	365.25"	24. h.	7916	1	1.	1	0	68.000	0.017
Mars	144	687.00"	24.64h.	4398	$\frac{7}{24}$	.43	$\frac{7}{10}$	1°50′	54.000	0.093
Vesta	223	1313.00"	unkn.	unkn.	unkn.	.18	unk.	7°9′	45.000	0.097
Juno	253	1586.00"	†27. h.	†1545	†$\frac{1}{125}$	.14	unk.	13°	42.000	0.254
Pallas	263	1680.00"	unkn.	†2280	†$\frac{1}{42}$	.13	unk.	34°30′	41.000	0.246
Ceres	263	1980.00"	unkn.	†1761	†$\frac{1}{90}$	.13	unk.	10°30′	41.000	0.076
Jupiter	490	4332.60"	9.94 h.	89170	1400	.037	$\frac{23}{100}$	1°19′	30.000	0.048
Saturn	900	10759.0"	10.27h.	79042	1000	.011	$\frac{9}{100}$	2°29′	22.000	0.056
Uranus	1800	30688.0"	unkn.	35100	90	.0027	$\frac{1}{5}$	0°49′	15.000	0.047

Those figures marked † are not certain.

Table II.—*Of Secondary Planets.*

Of the Moon.

Dist. from the Earth.	Inclin. of orbit to the eclip.	Revolution round the Earth.
Miles.	° ′	d h ′
240,000	5 50	27 7 43

Moon's diameter 2159. Bulk (that of the earth being 1) 1—49.

Period from change to change, 29d. 12h. 44′.

Of the Satellites of Jupiter.

	Distance from Jupiter.	Inclination of orbits to the orbit of Jup.	Revolution round Jupiter.
	Miles.	° ′ ″	d h ′
I	264.490	3 18 38	1 18 27
II	420.815	3 18 0	3 14 58
III	671.234	3 13 58	7 3 42
IV	1.180.582	2 36 0	16 16 32

Of the Satellites of Saturn.

	Dist. from Saturn.	Inclin. of orbits to the orbit of Sat.	Rev. round Saturn.
		°	d h ′
VII	119.627	30	0 22 37
VI	153.496	30	1 8 53
I	190.044	30	1 21 18
II	243.449	30	2 17 44
III	240.005	30	4 12 25
IV	788.258	30	15 22 41
V	2.297.541	42 45′	79 7 54

Of the Satellites of Uranus.

	Dist. from Uranus.	Inclin. of orbits to the orbit of Uran.	Rev. round Uranus.
		° ′ ″	d h ′
I	224.155	99 43 53	5 21 25
		or	
		80 16 7	
II	290.821	do.	8 16 57
III	339.052	do.	10 23 4
IV	388.718	do.	13 10 56
V	777.481	do.	38 1 48
VI	1.555.872	do.	107 16 42

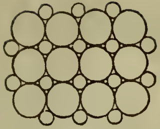
INDEX.

[The figures refer to the page.]

N. B. For the convenience of recitation, the figures are all repeatcd on separate leaves.

THE END.

Fig. 1.



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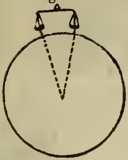
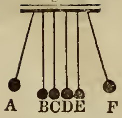


Fig. 3.

Fig. 4.



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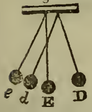

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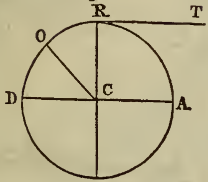

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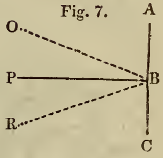

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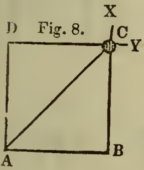


Fig. 9.

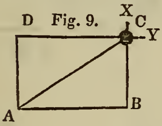


Fig. 10.

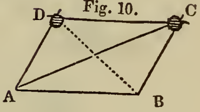


Fig. 11.

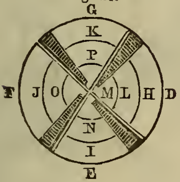


Fig. 12.

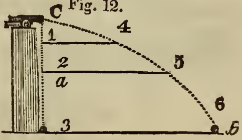


Fig. 13.

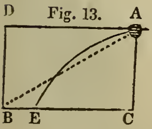
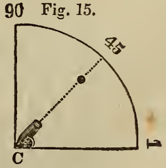


Fig. 14.

Fig. 15.



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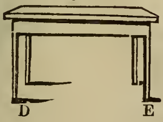

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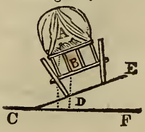

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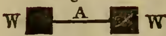

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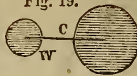

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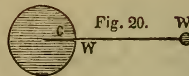

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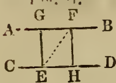

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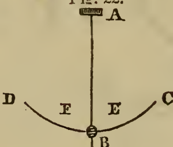

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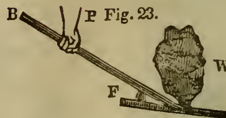

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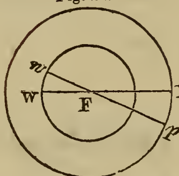

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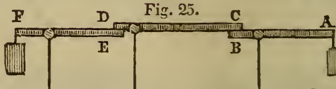

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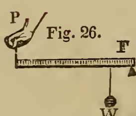

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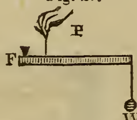

Fig. 28.

Fig. 29.

Fig. 31.

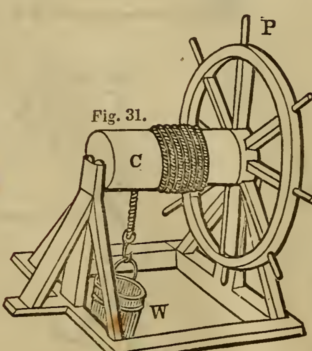

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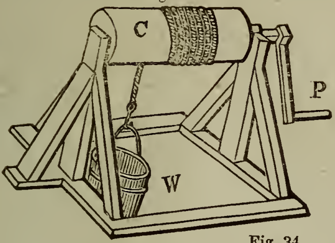
Fig. 32.



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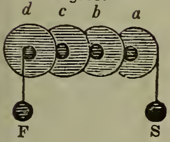

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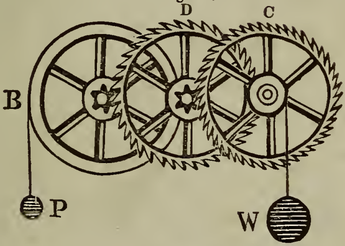

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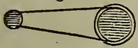

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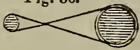

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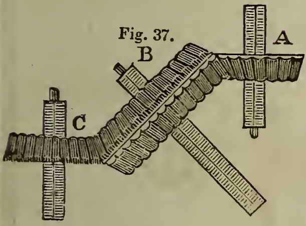

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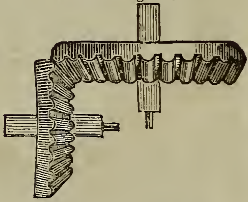

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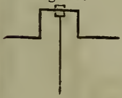

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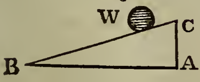

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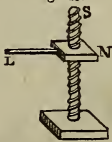

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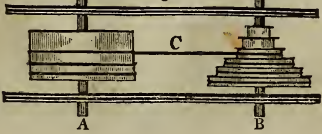

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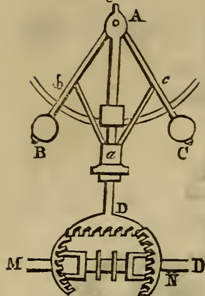

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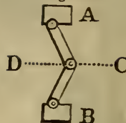

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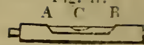

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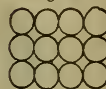

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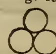

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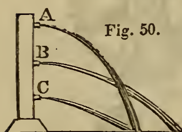

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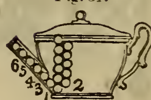

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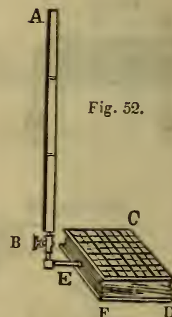

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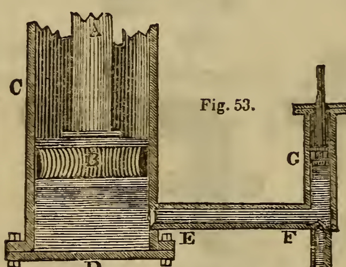

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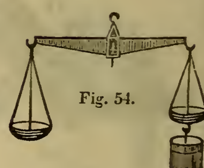

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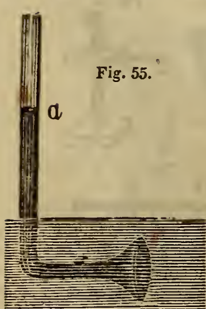

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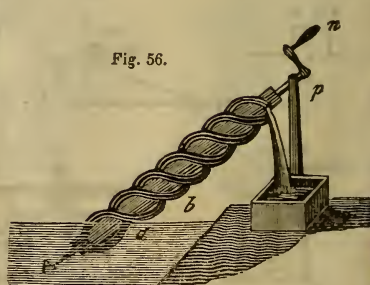

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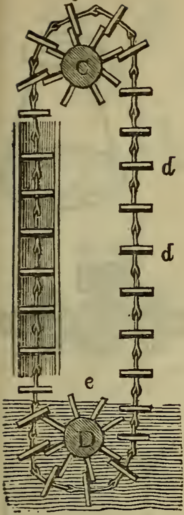
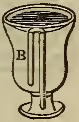


Fig. 58.

Fig. 59.

Fig. 60.



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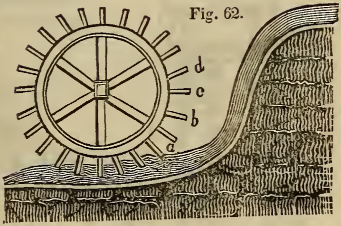

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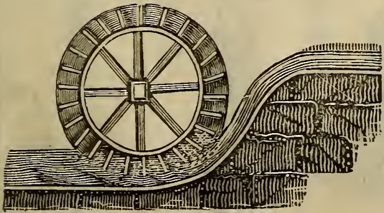

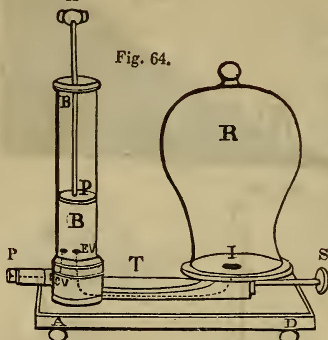

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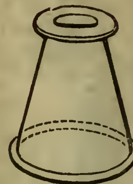
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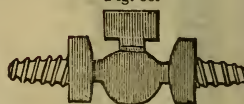
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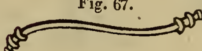
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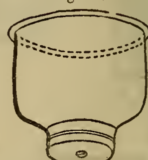
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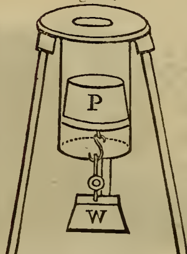

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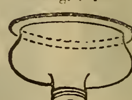
Fig. 70.


Fig. 72.


Fig. 73.


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Fig. 75.

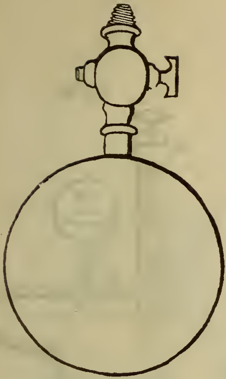

Fig. 76.

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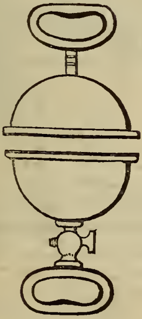

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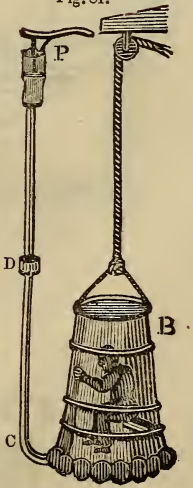

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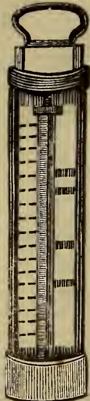

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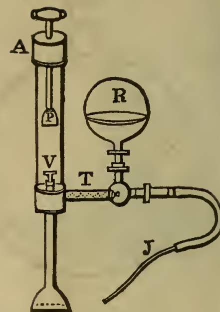

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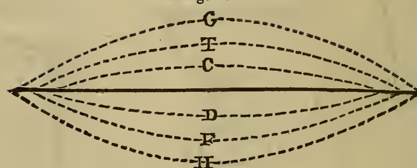

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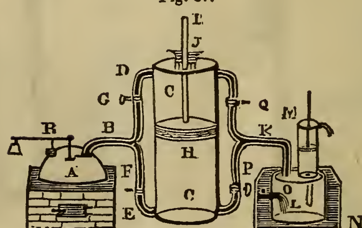

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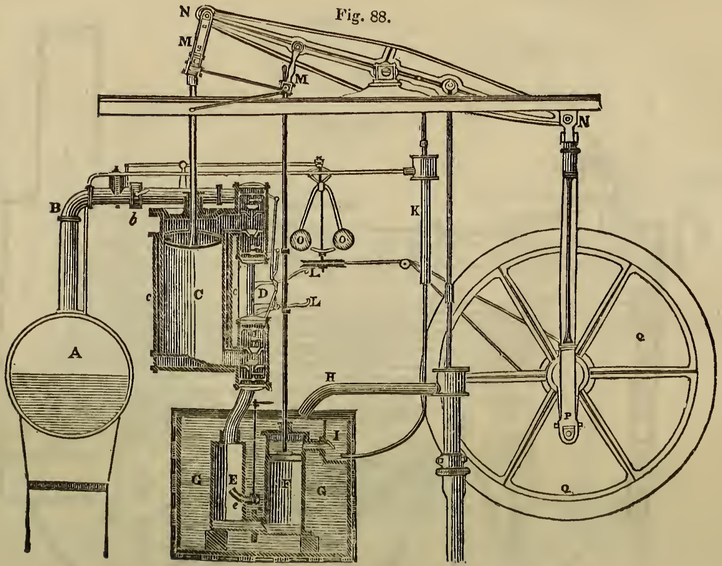

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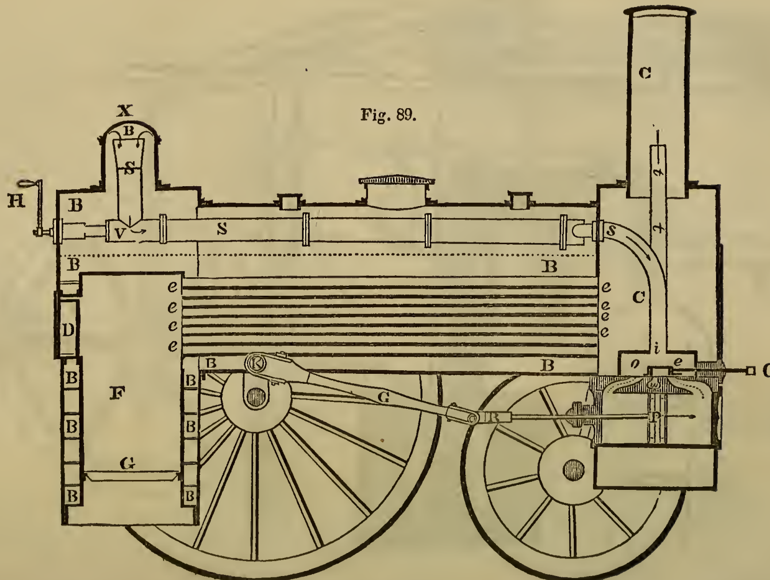

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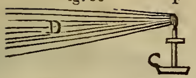

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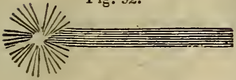

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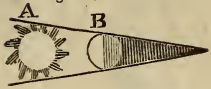

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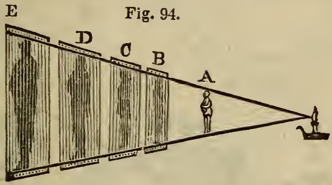

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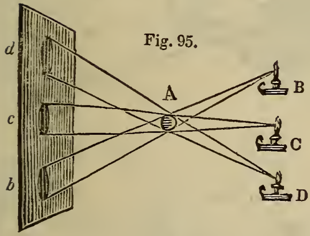

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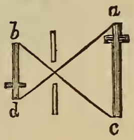

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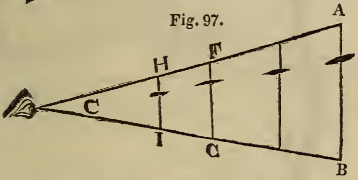

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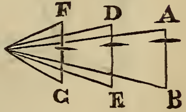

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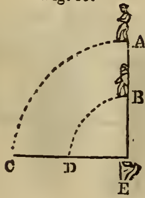

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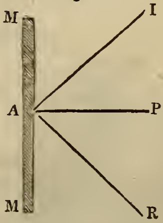

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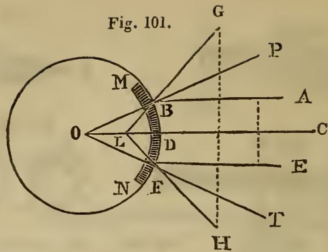

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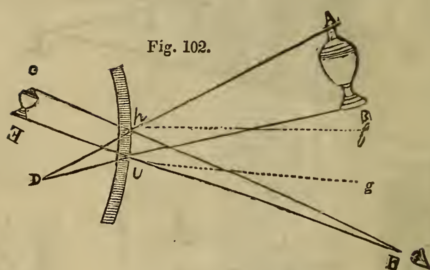

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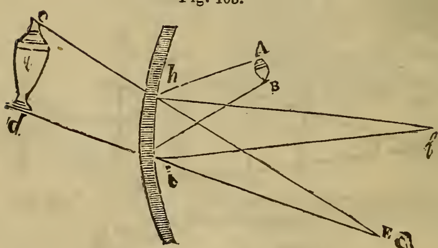

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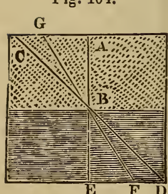

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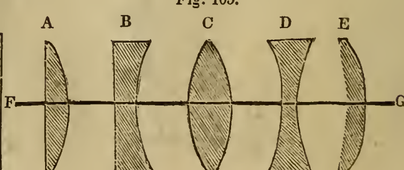

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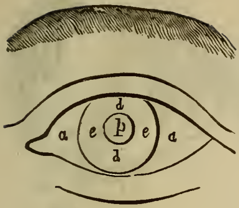
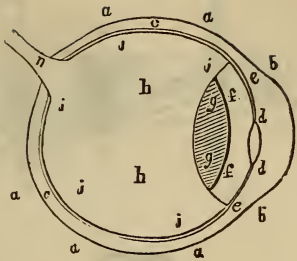


Fig. 107.



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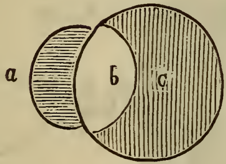

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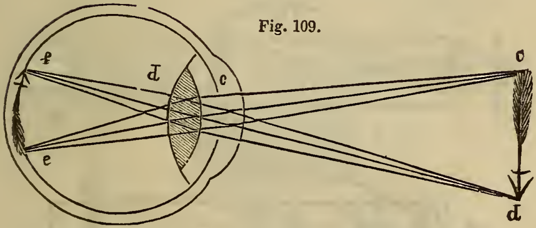

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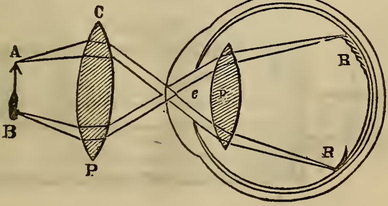

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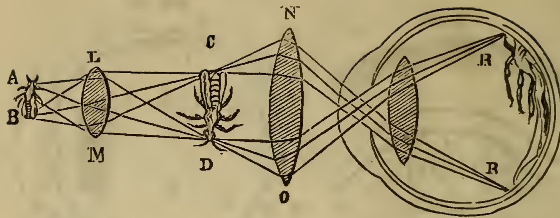

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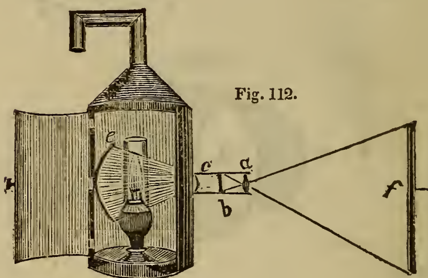

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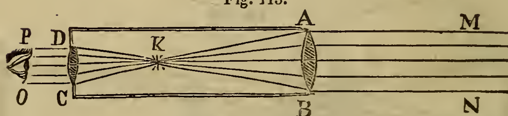

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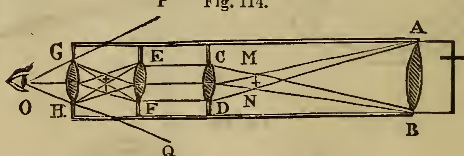

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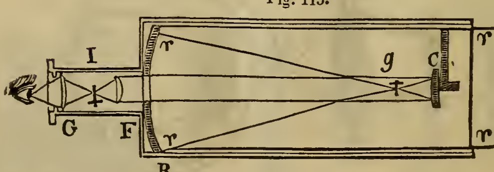

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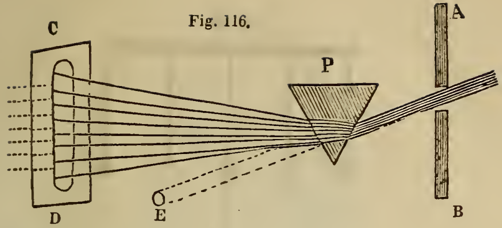
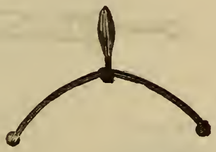


Fig. 117.

Fig. 118.



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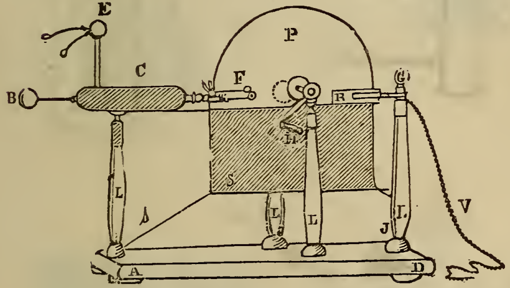

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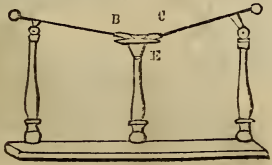

Fig. 121.

Fig. 122.

Fig. 124.

Fig. 123.

Fig. 125.

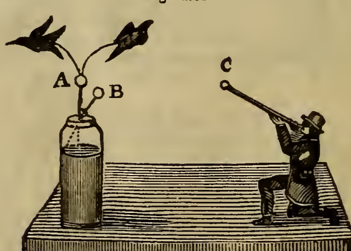

Fig. 126.

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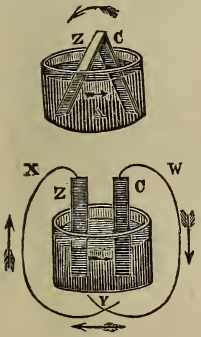

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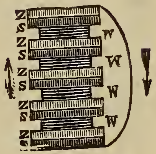

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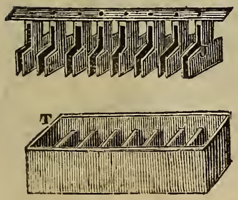

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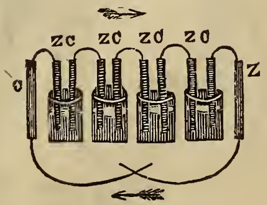

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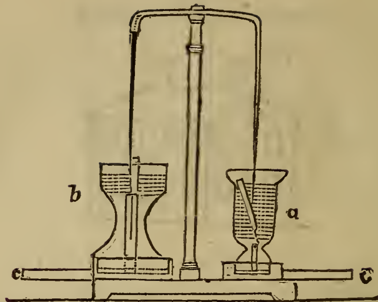
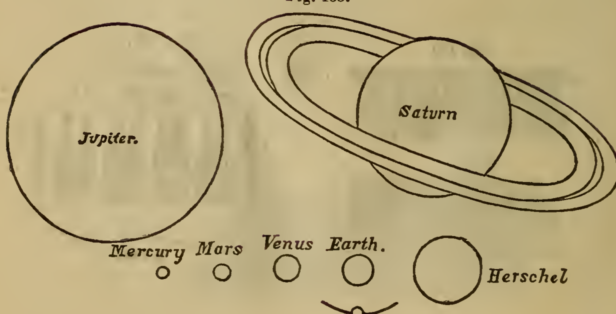


Fig. 132.

Fig. 133.



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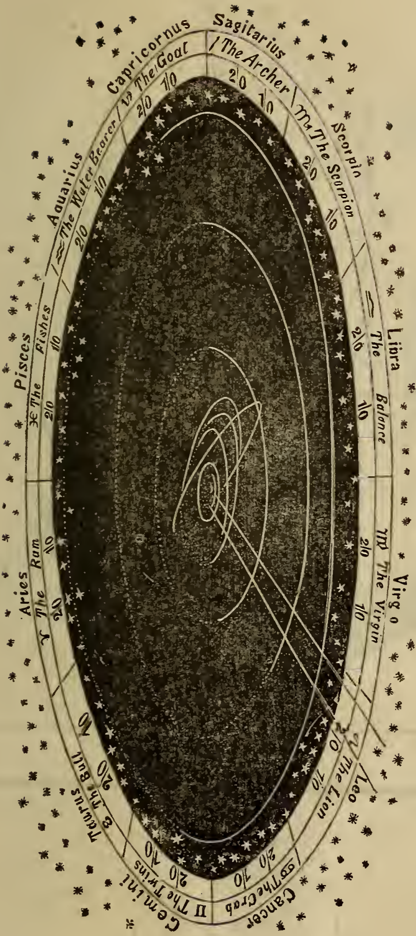

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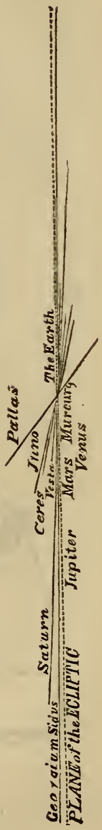

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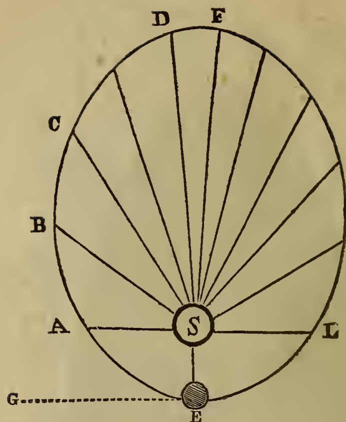

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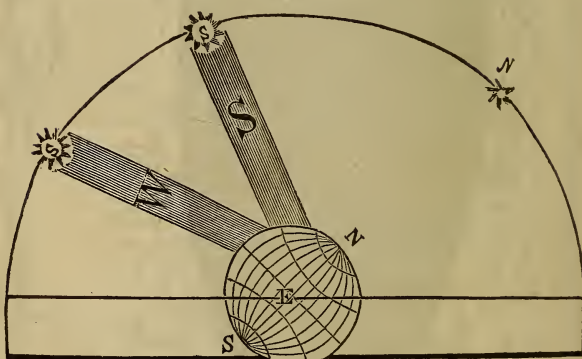

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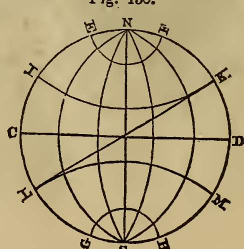

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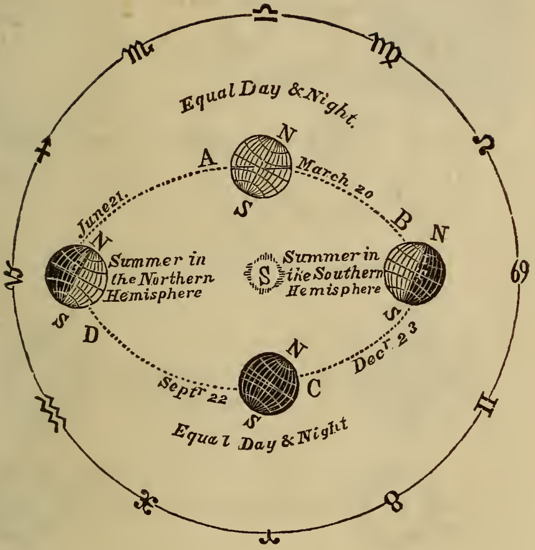

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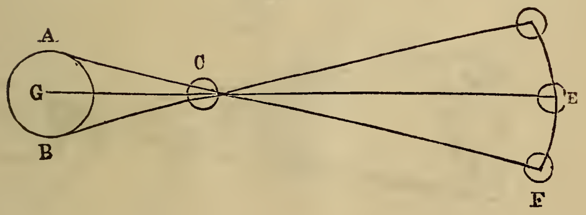
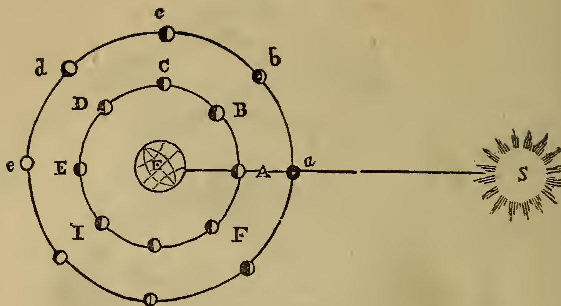


Fig. 141



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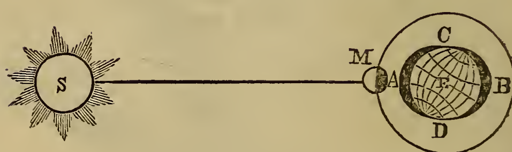

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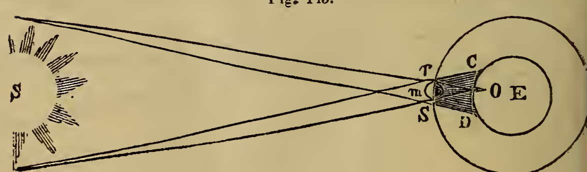

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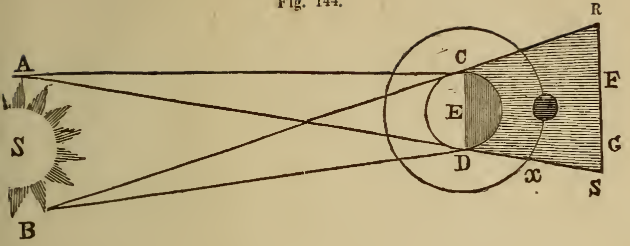

Fig. 145

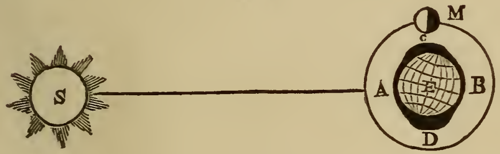

Fig. 146.